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Liberalizing Technical Education*

By H. P. HAMMOND

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Liberalizing Technical Education

The liberalizing of technical education has been a problem for years. It is not surprising that it has not been solved. The advancement of science and technology has been so rapid in recent years that adjustment of educational programs, even to their basic developments, has been a matter of constant and justifiable concern. Pressure to include more and more subject matter in already crowded curricula has been insistent and the improvement of their liberal element has been correspondingly retarded.

At present, when education in many fields is being re-appraised, this problem has come to the forefront among those for which solutions must be found. Issues growing out of events and trends of the past three decades, which have included the two most calamitous wars of modern times; a swing from the heights of inflation to the depths of depression; sweeping changes in social and economic concepts; emergence of the totalitarian form of government and its inevitable collision with democratic ideals; a trend from government by process of law to one by executive order—all of these, coupled with the profound changes that science and technology are producing in the entire social order, are giving point to the need for re-examining our educational programs. In particular, these conditions are making it clear that ways must be found to create among members of the scientific and technical professions a better understanding of the world they live in and have had so large a share in creating. "As citizens who have been privileged by society to receive higher education, they should be in position also to take a leading hand with others so privileged, in understanding and clarifying and determining action upon those political and social issues on which the future peace, freedom, and prosperity of the country depend." * This, as I conceive it, should be a recognized objective of technical education and is a major factor influencing its liberalization. I assume it was considerations such as these that led to the inclusion of this topic in today's program.

What does the term liberalizing technical education mean? It is often discussed in terms of the addition to an otherwise "narrowly specialized program" of a "cultural" element comprising such non-technical studies as history, economics, and literature, but

* Paper presented at the meeting of the Association of Land-Grant Colleges and Universities, October 24, 1944.

* From the presidential address of Robert E. Doherty, President of the Society for the Promotion of Engineering Education. JOURNAL OF ENGINEERING EDUCATION, Vol. 35, No. 1, September, 1944.

without any more specific objective than the general purpose of broadening the students' interests and outlook. The assumption that this means alone will serve the desired purpose appears to be based in part on the premise that technical and scientific subject matters have an inherent lack of cultural elements. It is scarcely necessary to argue before this audience that this assumption is utterly erroneous, though we must admit that the treatment of technical courses may be and often is such as to overlook their cultural values. If, instead of such a restricted conception of the liberalization of technical education, we imply the broad purpose of developing among students understanding and appreciation of the world around them in its various aspects—social, economic, political, scientific, artistic, moral—then it seems plain that the word *liberalizing* should have broader connotation. It should be applied to the planning and treatment of the student's entire program, not merely to one portion of it.

If this concept is accepted, what means may be sought to aid in enriching technical education? I offer three for consideration: (1) the approach to the teaching of scientific and technical courses; (2) a decrease in the rigidity of prescribed curricula; and (3) the provision of a group of courses having specific humanistic purposes of clearly defined significance in the education of technical students.

The first of these means can be discussed best, perhaps, by an illustration. I have chosen one from engineering because I feel more confidence in that field than I would in others. It is the teaching of heat power. In one approach to the teaching of courses in this broad subject, the treatment may be and often is strictly technical. Instruction does not get beyond the covers of prescribed textbooks. While principles of very wide significance in science and technology are employed, the student is led to see them chiefly as applied to specific situations or problems. He may become very proficient in reproducing such elements of subject matter and in solving stereotyped problems by specified procedures. But in so doing he will have acquired little power to analyze new problems or to solve them by applying the basic forms of the comparatively few fundamental laws which underlie the entire field. This approach to the teaching of the subject aims at closely specified efficiency in the routines of the course and realizes only to an incomplete degree on very valuable inherent attributes which the subject possesses as a medium of education.

In a second method of approach less strict reliance is placed on the textbook. The teacher aims chiefly to develop knowledge of basic *general* laws and uses them whenever possible. Thus, without neglecting the development of skill in solving specific problems, the subject becomes in large measure a vehicle for giving the student a thorough understanding of fundamental principles on which he can rely when he is confronted with situations which he has not previously encountered. This method requires skillful teaching but is one that ought to prevail widely in technical education.

However, one important element of value in teaching the subject we are considering is still lacking; that is, the opportunity to bring out the relationship that exists between the use of the energy of fuels in doing useful work and the profound effect this has had on our whole social order. Extensive

or elaborate treatment is not required to develop this aspect of the subject. Occasional references or questions at appropriate times intended to awaken the student's consciousness of the relationship of the course to economic and social problems will go a long way toward the desired end. If, in particular, this phase of the subject can be mentioned at the start of the course, it will help to orient similar future references. The simple question of which of the two contemporaries, James Watt or Napoleon Bonaparte, had the most lasting influences on society may serve to start students thinking about some of the most significant stages of the development of our industrial civilization. An introduction to these aspects of the general study of heat power can be used greatly to enrich the subject and thus to broaden the student's horizon.

This example will illustrate one important phase of the liberalizing of technical education. While my example was chosen from engineering, I am sure that many equally valid ones might have been chosen from any other field of applied science. Can anyone think, for instance, of any division of agriculture,* even among those most highly technical nature, which does not have vital bearings on our national economy and life and could be so treated as to promote the student's insight and interest in human affairs?

A second means of liberalizing technical education is by increasing the flexibility of prescribed curricula. It is inevitable, since such curricula deal with fields of knowledge that lie within more or less clearly defined boundaries, that they should follow well defined patterns. It is, in fact, a valuable educational asset of technical curricula that they possess the quality of coherent, integrated structure. Such curricula begin with the study of physical and mathematical science, continue with courses in applied science, and end with an introduction to the art of applying principles to problems of practice. Thus the student can be motivated from the beginning by discernible goals of his work. Freedom of election in such curricula is necessarily limited. However, I have yet to learn of a field of applied science in which some freedom of election, especially of the more advanced courses, is not both feasible and desirable. Time does not permit of adequate discussion of this matter here. It is mentioned as one of the means of freeing technical education from some of its rigidity and thus of aiding in its liberalization. How much of a technical curriculum can be allotted to electives? This will depend upon the nature of the field. In those with which I am familiar it may be from five to ten per cent or from 6 or 8 to 12 or 16 semester credits without injury to the integrated nature of the program. A part of these electives may very well be devoted to original or semi-original projects—perhaps an undergraduate thesis—in a field of interest which the student has developed under the guidance of some stimulating teacher. Qualities of resourcefulness and originality are ones that we are probably least successful in developing in students of applied science. If elective work can be used for that purpose it will increase greatly the value of our whole educational process. At any rate, it is a promising means of liberalizing our work.

But these two means alone—that is, broadening the treatment of scientific

*In the foregoing illustration, the name of Justus von Liebig might be substituted for that of James Watt to illustrate this point.

and technical courses and a somewhat greater proportion of electives—can scarcely be expected to serve adequately to liberalize technical education. Such methods will not serve to give the student a broad or well balanced conception of humanistic and social matters or to develop his interest in cultural matters lying outside of science and technology. The necessity remains of introducing a group of subjects having this explicit objective. To this group I shall apply the borrowed term *humanistic-social studies.*

The strengthening of this portion of technical education has recently been under consideration by a special committee of the Society for the Promotion of Engineering Education on Engineering Education after the War. While the report of this committee deals particularly with engineering, I believe that portion which deals with the humanistic-social content of the curriculum applies equally well to other fields of technical education. What follows, therefore, is based in part on that report.

Before discussing particular elements of educational programs, the report makes a number of general recommendations, pertinent to our present discussion, that may be condensed as follows:

(1) That undergraduate curricula remain of four years duration; that they be simplified in arrangement, lightened in total content, and devoted chiefly to the development of capacity to accomplish along specified lines through acquirement of the ability to use fundamental laws and principles in the solution of problems of practice. It is recommended also that the process of "pruning" the curriculum to the essential core of subject matter and skills be accompanied by transfer of some of the more advanced technical subject matters to the postgraduate period where they may be treated with a rigor consistent with professional purposes.

(2) That undergraduate curricula be made up of two major stems or integrated sequences of courses extending throughout the four years: one of these stems to be in science and technology and the other in humanistic-social studies. This plan of curriculum organization is believed to be better adapted to the nature and requirements of education in science and technology than is an arrangement in stages or divisions, the lower stage devoted chiefly to preparatory work in the sciences and humanities (or "general education") and the upper stage devoted chiefly to technology and more advanced science.

To pass now to consideration of the humanistic-social sequence of the curriculum, I believe that it is essential, in the first instance, to formulate explicit objectives for these courses in terms of knowledge to be acquired, abilities to be achieved, and cultural interests and tastes to be formed. It is not sufficient merely to allot time to this portion of the curriculum and then to choose from an available list of liberal arts courses a number that lie within the general fields of subject matter that it is desired to sample. Pressure for the retention of thoroughly worth-while elements of scientific and technical subject matter is too strong to justify inclusion of humanistic-social studies which do not serve clearly defined purposes in the over-all development of students of science and technology. The formulation of these purposes is therefore a matter of chief concern.

I suggest for consideration the fol-

lowing statements of these purposes. They are quoted from an earlier paper on this subject.*

"Development of the ability to read, write, and speak the English language effectively; to understand, analyze, and express the essentials of an economic, social, or humanistic situation or problem, and to appreciate its implications and relationships to the life and work of (a scientist or technologist).† There is also the goal of development of an adequate concept of the duties of citizenship in a democratic society; an acquaintanceship with the enduring ideas and aspirations which men have evolved as guides to ethical and moral values; and an appreciation of cultural interests lying outside the fields of (science and technology)." †

This statement constitutes a high purpose indeed for a division of education. It will be noted that it emphasizes the aim of developing ability to *do* and the capacity to *appreciate* rather than coverage of a specified amount of subject matter. I believe its accomplishment is possible within the present framework of technical education. As will be noted later, a few institutions are now taking steps to achieve this aim.

It is not sufficient, of course, merely to formulate the objectives of a division of education. Means must be sought to solve the problems incident to attaining them.

One of the most vexing of these problems is that of the allotment of time in the curriculum. This will have to be faced squarely. It is recommended that not less than one 3-hour course be provided in each of the 8 semesters, not including the introductory drill course in English Composition. This will require from one-fifth to one-sixth of the curriculum. If such an allotment is provided, it will mark a substantial gain in liberalizing technical education. Nevertheless, the desired result will not be attained by this provision alone. The most careful planning will be required to place this division of subject matter on as strong a basis as the technical courses themselves. The following suggestions are advanced as among the means that may aid in this effort:

Establish responsibility for planning and coördination of subject matter. This may have to be done through administrative direction instead of the customary type of departmental organization, at least until the work is well established.

Formulate the results sought as explicitly as possible.

Allot time in advanced years as generously as possible.

Use the most skillful teaching available.

Capitalize on the appeal of current interest.

It is necessary to select subject matters appropriate to the attainment of the objective as formulated. Those usually, and I think properly, associated with the humanistic-social stem are found in the fields of history, economics, and government, wherein knowledge is essential to competence as a citizen; and of literature, philosophy, psychology, and fine arts which afford means for broadening intellectual outlook.*

* See Introduction to the Report of the Committee on Engineering Education after the War, presented by H. P. Hammond at the 1944 Convention of S.P.E.E.

† *Engineer* and *Engineering* in the original version.

* From the Report of the Committee on Engineering Education after the War, JOURNAL OF ENGINEERING EDUCATION, Vol. 34, No. 9, May, 1944.

While the selection of subject matter is important, it is less important, generally speaking, than are methods of instruction. Formal expository methods are often used in humanistic-social courses. This appears to be one of the chief reasons why technical students do not like them and, in many instances, do not profit by them. Students of science and technology are accustomed to learn by doing: by solving problems, by performing experiments, by working on designs, or by writing reports. They are accustomed to using tangible media for achieving and expressing their results. They are thinkers, but they think best in association with doing things rather than listening to others talk about them. A method of instruction which places responsibility on the student himself and requires him to seek evidence, to weigh it, to arrive at a conclusion, and to express it in written or oral form will achieve a much greater degree of success than will listening to lectures or reading long sections of heavy textbooks without being required to do very much about it.

Methods of the type here advocated require greater effort and skill on the part of the instructor as well as more allotted time in the curriculum to achieve a given result, but they are likely to pay large dividends in student interest and accomplishment.

If provision of the type and amount mentioned above is to be made for humanistic-social studies, the question may be raised as to whether this can be done without sacrifice of essential vocational objectives. It must be remembered, of course, that the attainment of vocational proficiency is an unalterable aim of technical curricula. To solve this problem it is often suggested that the duration of undergraduate curricula be increased from four years to five years. The committee referred to above concludes that the solution should not be sought through increasing the duration of collegiate education for *all* technical students, but rather by simplifying and making more fundamental its undergraduate stage, transferring some of the more advanced technical subject matter to postgraduate years, and providing for larger enrollments in a fifth year and subsequent years. In view of an accelerating trend in technical education, this recommendation may sound like a rationalization. During the twenty-year period from 1920 to 1940, postgraduate enrollments in engineering, as a sample, multiplied more than five-fold and reached a total of over 5,000. Further development of this evolutionary trend, which has reached virtual completion in chemistry, appears to be a more rational and approprite process than would be the enforced attendance by all undergraduates for a longer period. It appears to be more in keeping with the interests, abilities, and financial capacities of many students, as well as with the types of positions and responsibilities of their later careers. It is therefore recommended that in providing more time for humanistic-social studies and elective courses close attention be paid to the relative importance of *all* portions of the curriculum and that elements which cannot be clearly shown to produce a thorough grasp of fundamental principles or to creating skill in the art of applying them should be omitted.

Instead of weakening the undergraduate curriculum, it is believed that the result of this process will be to strengthen it all along the line.

It is a fair question to ask how much

has been done toward the realization of the objectives here discussed. Have any colleges actually put into effect programs of technical education aiming to accomplish the purposes contemplated? Have they made the time allotments suggested? The answer is "yes," such is the case in several institutions: There is no single element in the proposed program that has not been adopted in one or more institutions and the main objectives are being sought in several. Without making a complete canvass, the following may be mentioned: Brooklyn Polytechnic, California Institute of Technology, Carnegie, Case, Cooper Union, The Pennsylvania State College, Purdue University, Princeton, City College of New York, Michigan State College, Florida, Stanford University, Stevens Institute, and, most recently, the Massachusetts Institute of Technology.* It is of some significance to note that the institutions in which time for the liberal element in technical education is now being most adequately provided are certain of the separately organized schools of technogoly, rather than the universities and land-grant colleges. If any single reason were to be assigned to this, it might be that in a school having a unified type of program and a faculty organized in a single group, there is likely to be more centralized control over non-technical courses than in an institution of university type.

As previously stated, however, the mere provision of sufficient time for humanistic-social studies is not in itself the answer to any phase of the problems of technical education, and particularly to the one under discussion. There remains the necessity of obtaining the courses, teachers, and attitudes on the part of the students and faculty which will aid in achieving desired results. Experiences indicate that this will require time, energy, and persistence as well as tact and ability.

* Of these institutions, 7 are privately endowed polytechnic institutes, 2 are privately endowed colleges and universities, 1 is a municipal college, and 4 are land-grant colleges and universities.

The Wind Tunnel in Undergraduate Instruction and in Research

By WILBUR C. NELSON

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The current program of aeronautical research—greatly intensified by the demands of aerial warfare—has resulted in many millions of dollars being spent upon the construction of various types of wind tunnels. The National Advisory Committee for Aeronautics, the Army Air Force, the Navy, and several industrial groups are now operators of wind tunnels whose size and complexity were hardly thought possible a decade ago. The taxpayer may well reflect with some degree of satisfaction that federal funds used in this manner represent a long-term investment in both immediate and post-war aerial supremacy with its accompanying peace time advantages. This rapid growth has, with a few notable exceptions, left the colleges and universities of this country with wind tunnel equipment which is extremely limited by comparison. In general, we may divide this equipment into two distinct categories. It is the purpose of this paper to present a qualitative discussion of:

(1) the merit of the small, undergraduate wind tunnel for instructional purposes.

(2) the utilization of the relatively small research wind tunnel in the graduate program.

* Presented at the 52nd annual meeting, S.P.E.E. (Aeronautics), Cincinnati, June 22-25, 1944.

The undergraduate wind tunnel

For the purpose of definition herein, a small undergraduate wind tunnel will be considered as atmospheric with a test section area approximately 10 sq. ft. or less and a maximum velocity 100 m.p.h. or less. The research wind tunnel is considered as atmospheric with a test section area approximately 65 sq. ft. and a maximum velocity well beyond 100 m.p.h.

A recent U. S. Office of Education bulletin lists 63 colleges and universities as offering "more than three courses in aeronautics." This group and others contemplating such instruction will be directly concerned with equipment of the undergraduate instruction type. Upon first thought the use of such equipment may seem quite futile when compared to the large wind tunnels currently employed elsewhere, or at the best a sorry compromise between present-day reality and past tradition. The general objectives of engineering education may well be reviewed in order to evaluate our goal. The ability to think analytically in terms of basic scientific principles and to obtain an acceptable solution to a current engineering problem is fundamental. All aeronautical engineering work in aerodynamics, structures, and mechanisms is directed to that end. This involves not only a classroom study of theory

and test data but a well-balanced laboratory course substantiating and re-emphasizing the theory and also developing practical testing techniques. The necessity for obtaining sufficient empirical test coefficients to bridge the gap between theory and practice is driven home.

No other laboratory device could be more useful in the study of aerodynamics than the wind tunnel. It is quite significant that Wilbur and Orville Wright in the fall of 1901 built their first wind tunnel and found large errors in all previously published data concerning center of pressure and force variation on flat and curved plates. Their wind tunnel data pointed the way to a principle of control which is still used in the modern airplane.

The main elements of a wind tunnel, in which the test object is held stationary and a controlled stream of air flows past it, are typified in the Iowa State College wind tunnel. The design features of a closed return duct, electric prime-mover, remote control of test model position, six-component balance system, and wide velocity range are common in this and much larger installations. Laboratory objectives include, of course, attainment of the highest degree of accuracy possible with the equipment available. This implies careful and intelligent operation. Repeating an entire test because of carelessness on the part of one member of a test crew emphasizes team work and interdependence. The rotation of crew chiefs develops leadership. The student studies principles governing wind tunnel design; learns the instrumentation and testing techniques; and runs a series of tests illustrating airfoil action, principles of drug reduction, and airplane performance and stability. Extrapolation of test data to full scale is studied and applied. A knowledge of sources of error and their magnitude leads to an understanding of the necessity for much larger and more extensive equipment in the industrial and governmental research fields.

Just as laboratory strength testing is inseparable from a study of structures and just as laboratory engine testing is inseparable from a study of mechanisms, so an adequate laboratory test program is inseparable from an undergraduate study of aerodynamics. The trend towards a reduction in the large amount of "shop" time in the undergraduate engineering curriculum may well be balanced by the inclusion of adequate laboratory testing time where the emphasis is not upon manual dexterity as such but rather upon the design and operation of test equipment to obtain reliable data regarding the behavior of the test object.

All this does not imply, however, that the construction and operation of a wind tunnel assures an adequate laboratory course in aerodynamics. With careless construction, poor operation, and incompetent instruction both in the laboratory and in the preceding aerodynamics class work, this equipment will be of little value. Neither is it necessary that a large amount of time be spent in the aerodynamics laboratory. A minimum of eighteen laboratory periods is probably sufficient.

The research wind tunnel

The research wind tunnel is in a distinctly different category from the undergraduate wind tunnel. The undergraduate student may run one test in the larger research wind tunnnel but his experience with it is usually limited to a demonstration of the equipment. The exceptional senior may be given the opportunity to assist in the research

program but only as an assistant under full supervision. While both wind tunnels are relatively small, the research installation is definitely larger and incorporates the utmost refinement in its construction, balance system, and speed control. Here again one may question the utility of such a piece of equipment where the research student or professor does not have at his command such facilities as a velocity range approaching the speed of sound; a temperature and pressure control of the airstream; or a test section of such proportions that the model size approximates or equals full scale. All of the preceding factors combine to permit testing at full-scale Reynolds Number and simulated high altitude conditions, which is a combination of admittedly prime importance for research concerned with high-speed military aircraft.

However, flight at relatively low velocities also demands much in the way of the research. One has only to make a casual survey of the aerodynamic field to realize the wide variety of phenomena that exist outside the sphere of high-velocity, stratosphere flight and which are worthy of continued attention. Boundary layer control; turbulence investigation; propeller, blower, windmill, and rotor testing; airplane and helicopter performance and stability; control surface characteristics; flow visualization—these and many other problems afford a fertile field of research in a velocity and model range well within the capacity of the university research wind tunnel. Indeed, a survey of technical literature will clearly show that these topics are being vigorously investigated. It is to be hoped that the entire field of low-velocity flight will come in for extensive research and development in the near future because of its direct relation to the private flyer and the need for marked advances in order to bring private flying into its own. It should also be noted that in the overall view it is a healthy condition to have several independent organizations working in the same general field of research, particularly when the academic approach is not so highly conditioned by the need for an immediate practical solution as is often the case in industry. In conclusion, then, the academic wind tunnel research program should continue to maintain a high plane of usefulness despite its new relation, in most instances, to the industrial and governmental laboratory equipment.

An Aeronautics Option in Civil Engineering*

By A. S. NILES, JR.
Stanford University

While many American engineering schools have sufficient students and faculty interested in aeronautics to justify a separate curriculum in aeronautical engineering, this is not true of the majority of such institutions. Some of these schools may have no desire to give aeronautical training, while in others a certain amount of time is allocated to aeronautical subjects which form the content of an aeronautical option in one of the more general engineering curricula. The aim is to produce a graduate who, though not a graduate aeronautical engineer, would have sufficient knowledge of aeronautical problems to be of value to a manufacturer or operator of aircraft. Practically all "aeronautics options" offered at present are options in a course in mechanical engineering. The aim of the present paper is to point out that the civil engineering department is an equally suitable location for an aeronautics option and to encourage any civil engineering instructors who may desire to give work in this field.

The inclusion of aeronautics in mechanical engineering is due only in part to the character of the work of the aeronautical engineer. To a very great extent it is the result of what may best be termed historical accidents. As flying became practical and airplane design passed from the inventor to the engineer a number of wide awake and far-seeing university men became interested and began to offer courses in the field. Usually these were "hobby courses" given in addition to the instructors' regular work. As aeronautical engineering became more important and the number of students taking aeronautical work increased, more and more time was devoted to the subject, and regular curricula and departments of aeronautical engineering were established in some schools. In others the recognition of aeronautics has gotten only to the stage of offering aeronautics options. The courses offered by the pioneers were naturally given in their own departments, and when an aeronautics option was established it was made an option in the branch of engineering with which the pioneer was connected. As it happened, most of these pioneers were mechanical engineers whose initial interest in aeronautics was the result of previous work on internal combustion engines or screw propellers. Although the structural theory associated with aircraft design is equally interesting to the structural engineer, it happened that few, if any, civil engineering teachers became sufficiently interested in aeronautics to establish aeronautical courses or options.

Though civil engineering depart-

* Paper presented at 52nd annual meeting, S.P.E.E. (Aeronautics), Cincinnati, June 22-25, 1944.

ments showed little interest in aeronautical instruction, in the days before there were sufficient graduates in aeronautical engineering, much of the structural and aerodynamic design of airplanes was carried out by men who had graduated in civil engineering. In fact when Professor Newell and the writer compiled a list of chief engineers and chief stress analysis men of the important American airplane companies, about 1925, we found that the majority had graduated in civil engineering.

In view of this history it appears unfortunate that the civil engineering student is allowed to get the impression that airplane design is no more in his field than the design of hydraulic turbines or radio sets. It is quite true that the training of the civil engineer is inferior to that of the mechanical engineer in respect to the design of aircraft engines and much of the detailed construction of the modern airplane. The average civil engineering course, however, is stronger than the mechanical in structural theory and is thus a better foundation for much work in stress analysis. When it comes to aerodynamic theory and performance estimation the two branches are about equal. Aerodynamics is a branch of fluid mechanics which is best taken up after the student has some acquaintance with the related branch of hydraulics. The latter subject is given by the civil engineering department in some schools and the mechanical engineering department in others. It cannot be said to "belong" unquestionably in either. From the viewpoint of subject matter the civil engineering department is as logical a location for an aeronautics option as the mechanical engineering department.

In an aeronautics option in either civil or mechanical engineering there should be at least a one-year course in aerodynamics and its applications, and a one-year course in the aeronautical applications of structural theory in addition to the basic courses of the curriculum in which the option is established. The graduate of such an option in either civil or mechanical engineering should find himself competent to carry his load in either the aerodynamics or the stress analysis work of an airplane manufacturing company. The graduate of a mechanical engineering option would have the advantage in work on power plants and on detail design and layouts, though a good man graduating from a civil engineering option could soon adjust himself to work in the latter field. On the other hand the graduate of the civil engineering option would have the advantage in connection with airport and airway work.

At the present time the writer knows of but one aeronautics option offered by a civil engineering department, and it was organized very recently. He believes it worth while to discuss this option in some detail since it illustrates what can be done in a representative institution, and also what the writer considers to have been errors in designing its curriculum. In this option the student takes the regular civil engineering course for the first three years. In the last year he must take 35 semester units. Of these 16 are required of all civil engineering students and, according to the catalogue, the remaining 19 are for the option subjects. Actually, however, 5 of the 19 units are optional only in respect to the semester in which they are taken, leaving only 14 units for aeronautics. The fourth year program in detail is as follows

FIRST SEMESTER

Course	Units
CE 40 Water Supply Engin.	4
CE 64 Structural Design	5
CE 99 Inspection Trip	0
CE 10 Navigation	3
CE 67 Stat. Indet. Struc.	3
ME 33 Aeronautic Engin.	3

SECOND SEMESTER

Course	Units
CE 41 Sewerage	3
CE 65 Structural Design	4
CE 24 Airport Design	2
CE 66 Earth and Masonry Struc.	3
CE 70 Airplane Structures	3
CE 90 Contracts and Specs.	2

Courses CE 40, 41, 64, 65, and 99 are required of all civil engineering students in the semester listed. The other courses are those of the option. CE 66 is required of all options and CE 90 of all but the sanitary option. Why the sanitary option men get by without the course in contracts I do not know. Perhaps the writing of contracts for sewers in that state is left up to the political bosses. CE 67, statically indeterminate structures, is also required of the students in the structural option. The other courses listed are strictly aeronautical option courses.

A little earlier it was stated that the aeronautics option should include a full year of aeronautical structural theory and a full year of aerodynamics. In the program under consideration the time devoted to these subjects is apparently only half that amount. In so far as structures is concerned, however, with 9 units of structural design and 3 units of statically indeterminate structures, the deficiency is probably more apparent than real. At Stanford for the last dozen years the same basic course in statically indeterminate structures has been given to both aeronautical and structural engineering students with very satisfactory results. If CE 67 of the curriculum under study is given with suitable consideration to the needs of the aeronautical as well as the structural option students, there is no need to ask for more structural theory. The curriculum might be made of more value to the aeronautical student, however, if the subject matter of the second semester course in structural design, CE 65, were given an aeronautical flavor. If it were considered inadvisable to give a separate course in airplane detail design, some of the problems used in the course offered to all civil engineering students could be aeronautical in character. The resultant broadening of the scope of this course would be of advantage to the civil engineering students in all of the options. For the non-aeronautical student these problems would give highly desirable practice in design where more than usual care must be used to avoid excess weight.

The three units allotted to aerodynamics in the curriculum under study is not enough, and another three units should be offered in the second semester. In the opinion of the writer this could be done most advantageously by omitting the course in navigation and moving Earth and Masonry Structures (if it is to be retained) to the first semester. Though navigation is an interesting subject, it has practically no relation to airplane design, and little, if any, to airport design. What little might be necessary in connection with airport design could well be included in the course in that subject. The time allotted to navigation would not make the student a competent navigator, even if he happened to desire to be one, while if it were devoted to aerodynamics it could make the difference between a superficial and a worth-while introduction to the subject.

Another possible change for the better would be to omit the course in Earth and Masonry Structures and substitute a first semester course in aircraft power plants and propellers. So far as the airplane designer is concerned a course in "Dams, retaining walls, bridge piers and abutments, shallow bins, deep bins, culverts, arches, foundations, and soil mechanics" as CE 66 as officially defined in the catalogue, is something of far less value than one in power plants and propellers. The airport designer, however, would need some of these subjects, and the student in the aeronautical option might be allowed to choose between the two courses.

On the whole the curriculum under discussion would provide a student a satisfactory training for entry in the field of aeronautical engineering. Its only major defect is lack of time devoted to aerodynamics and that could easily be remedied by substitution of more of that subject in place of Navigation. If such a change were made and the instruction retained at the standard of the institution at which it is offered, it should prove an excellent training for entry into the aeronautic field.

Some may feel that even with the suggested changes, the student taking the curriculum under discussion would not have had enough aeronautical engineering to make the curriculum worth while. Stanford experience, however, is to the contrary. Although Stanford students who complete the requirements for the degree of Engineer in Mechanical Engineering: Aeronautics take much more aeronautical work than is called for in the above suggestions, there have been a fairly good number who have entered the aeronautical industry with approximately the amount of time devoted to aeronautical subjects that is called for in the suggested option. These men have not found themselves unprepared, but have fitted in rapidly, and are having successful careers in the industry. There is no reason why students getting approximately equivalent training in other schools should not do as well.

The object of these remarks has been to point out that a school with a good department of civil engineering, by the addition of a very small number of courses in aeronautical subjects, is able to offer a worth-while option in aeronautical engineering. All the additional courses required could easily be given by a single faculty member, though it is unusual to find a man who is equally interested in aerodynamics and in airplane structures. It is therefore hoped that these comments may fall upon receptive ears and that when conditions become more normal, there will be more than one civil engineering department offering aeronautical options. Such a result would not only be good for those departments, but also for civil engineering students who decide in their last year or two of school that they would like to enter the aeronautic field.

Some Suggestions on the Teaching of Structural Analysis and Related Subjects

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The following notes are based on the author's experience in the aircraft industry over a period of more than fifteen years, most of which was spent in close contact with the structural phases of airplane design. During this period the airplane has changed so much that entirely new methods of analysis and engineering procedures have been evolved; even the organization of engineering activities has changed. It might therefore be of interest to mention some of the more important developments and trends, and to discuss the influence of such developments on aeronautical engineering education.

The general influence of aeronautics on structural theory and design is by this time well understood and needs no further emphasis. During the past few years many excellent technical papers and textbooks have been written, covering such subjects as thin-web shear beams, buckling of plates and shells, stability of frameworks, and prevention of fatigue failures. In addition, there now exists a wealth of information in the form of restricted reports of the National Advisory Committee for Aeronautics, War Metallurgy Committee, and other government agencies. Most of this material may be regarded as the extension of previously known structural theories; it should become generally available at the end of the war and much of it will find its way into the curriculum in due course.

Less attention seems to have been given to the influence of aircraft problems on the more elementary phases of structural analysis, such as mechanics and strength of materials. It may therefore be worth while to mention some specific examples and to offer some suggestions of a practical nature. Before doing this, however, it would be well to consider the overall picture, which has been clearly stated in a letter from Professor Hardy Cross, as follows:

"There are clearly now in mechanics three rather different approaches or philosophies. One is the rather ancient and traditional one of the structural designer. The second is that of the machine designer, and now a third appears to have entered the field, that of the airplane designer. I do not know that it is important from an industrial point of view that they be reconciled. I do think it is important from the educational point of view that they be reconciled. I am told that the airplane designer wishes consistent design with a uniform factor of safety for ultimate loads. Certainly this is not the tradition in the field of structural design. I am a little confused as to what the philosophy of machine design is, or in fact whether there is one. I hold no brief for any of the philosophies. The objection to any change, of course,

is that it tends to scrap millions of dollars worth of experience in the field."

In answering Professor Cross' letter, I stated in part:

"You are quite right about the three different approaches or philosophies in structural design. The aircraft people have gone their own way for many years, with the result that there is a large gap which makes it difficult for us to take advantage of much valuable work in other fields, and vice versa. The common ground seems to lie in dealing with the *actual behavior* of a structure under load; *i.e.*, at what loads does it buckle, yield, tear apart; how many repeated loadings of given intensity will it stand. If the structural experts could agree on this approach, the values of factors of safety and working stresses could be left to the various special design groups and government agencies."

In introducing the student to the study of structures, it would seem important to emphasize the fact that there are several different systems of handling factors of safety and working stresses, but that all are based, directly or indirectly, on the prediction of the actual behavior of the structure under load.

So far as possible, the student should be given an opportunity to apply and check the basic laws and formulas, through laboratory experiments. He should observe actual failures of different types of construction, after having estimated the failing load by analytical methods. Next to the first flight test of an airplane, there are few moments more tense than those when the final increment of load is being added in a full scale destruction test of the structure. The stress analyst knows full well that premature failure may cause serious design changes and production delays; yet he is equally concerned lest the structure take much more load than required, which would reveal poor structural efficiency.

A related subject which deserves much emphasis in structural teaching is the matter of non-uniformity of material properties. The student should be given a clear understanding of the manner in which the mechanical properties of materials may be expected to vary from piece to piece and from lot to lot. This can be illustrated by means of frequency distribution diagrams. Much information of this type exists in the laboratories of the material producers, but relatively little is ever published. It might be worth while to have the student perform some laboratory experiments involving the testing of a fairly large number of specimens, plotting the frequency distribution curves, and selecting suitable design values (both ultimate and yield stresses could be included). If actual testing is not feasible, the student could be given some tables of typical values to work with.

An important but much neglected subject is the correction of test results to "standard." For aircraft structures this can become very complicated and requires a thorough knowledge of the mechanism of failure, particularly for parts which fail through buckling. A typical example from aircraft work is the testing of small panels representing portions of the wing or fuselage. Here we must take into account the influence of E (modulus of elasticity), yield stress, end-fixity, and other factors. Non-dimensional presentation of data furnishes the best general solution to this problem. Structural engineers, unlike aerodynamicists, have been slow to utilize non-dimensional methods. The final solution of all problems involving material variations lies in the

use of non-dimensional stress-strain diagrams. This has recently been facilitated by simplified methods of presenting stress-strain diagrams mathematically.

An excellent laboratory experiment for students might be built up around the testing of several compression members of different lengths and the reduction of the resulting column curve to a "standard" stress-strain diagram and to a specified coefficient of fixity.

In dealing with external loads, the methods of collecting or "summing up" forces in space should be made more general. In the past it has been customary to cover this during the treatment of beams, by working with shear and bending moment diagrams. This is logical when applied to simple trusses and frameworks, but in airplane wings, for instance, we have a three-dimensional problem involving bending (or torsion) about three axes. To take care of this it is convenient to refer all loadings to a "load axis," from which the resultant loads at any point may later be transferred to a "structural axis" (usually passing through the centroids of cross-sectional area). It is important to note that this structural axis sometimes is not accurately defined until the structure is almost completely designed. The use of an arbitrary load axis permits the completion of the external load analysis without any knowledge of the internal structural arrangement.

The principles involved in force summation are, of course, very simple; the important points to emphasize are systematic tabulation of the data, consistency in sign conventions, and step-by-step checking. A laboratory experiment could be set up by using a cantilever beam of irregular shape (such as a bent tube), hanging weights at different points, and computing the reactions about designated space axes at the root. It would even be possible to support the root of the beam in such a manner that the computed reactions (moments) could be applied to balance the beam and check the computations.

If the bending moments acting on a given cross section of a wing or fuselage are computed, it is very unlikely that the resultant moment will act about one of the principal axes of the cross section. It is therefore most important that the engineer understand and be able to apply the theory of unsymmetrical bending. This should be covered when the beam theory is being explained, not left to be treated as an advanced problem. Very serious errors can be made by failing to handle unsymmetrical bending in the proper manner.

In analyzing for unsymmetrical bending, aircraft engineers have found it expedient to eliminate the determination of the principal axes and to work directly with the reference axes used for computing the section properties. This very useful method, which involves modification of the symmetrical bending formula ($f=My/I$), has not been sufficiently emphasized, although it has been available for a relatively long time.

To impress the student with the importance of the unsymmetrical bending theory it would be desirable to conduct a laboratory experiment in which the strains caused by bending would be measured. A beam of rectangular cross section might be employed and the direction of the applied bending moment could be varied by changing the direction of loading. It would be possible also to show the effect of unsymmetrical bending on the stiffness, by measuring the deflection produced.

(This point is often overlooked in design.)

Incidentally, the treatment of bending and torsional moments by means of vectors is practically mandatory in work of this type. The use of the plane of action to designate the moment should be avoided entirely. This is too often confused with the plane of the resultant shear load, which is not necessarily coincident with the plane of the resultant bending moment.

The use of the conventional shear stress formula (SQ/bI) is highly questionable when the cross section of the beam varies along its length. It should be emphasized that the classical theory is based on the assumption of uniform cross section. Serious weaknesses in the structure may go unnoticed if the classical formula is used for beams having rapid changes in cross section, such as often occur in airplane wings. The student should be made to realize that the shear stress (or, more properly, the shear flow) is governed entirely by the change of axial loads within the beam; if this is once determined or calculated, the shear distribution must agree. The shear stress equation is therefore to be regarded as of secondary importance, in comparison with the equation for axial stress due to bending ($f=My/I$).

Perhaps the most serious shortcoming of the older methods of teaching structures was the lack of information on combined loading conditions. The subject of combined stresses has been greatly clarified by the use of Mohr's circle. But the problem of *allowable* combined stresses has long been one of the weakest links in aircraft structural analysis. Each of the simple loading conditions has been explored in great detail, but in an actual airplane structure we are very lucky to find a case of simple loading.

An entirely workable answer to this problem has been found in the "interaction curve," or "stress-ratio" method. This method makes full use of what is already known about the simple loading conditions. It is also general enough to cover almost any theory of failure and it is ideal for presenting test results *without* any theory. (One of the first discussions of this method will be found in an article entitled "Stress Ratios," *Aviation*, June 1937.)

The interaction curve method could be illustrated by simple laboratory experiments. Using round tubes for specimens, the student would determine the ultimate moments for simple bending and for simple torsion. Then tests would be made for different combinations of bending and torsion. The results would be plotted in the form of an interaction curve.

Column theory offers many opportunities for interesting laboratory experiments. One thing which could easily be demonstrated is the fact that the critical compressive load is very closely related to the lateral stiffness of the column. There is a story about an old-time designer who selected tube sizes for compression members by placing the tube across two boxes and bending it with his knee. This method is actually far more logical than approaching the problem from a *stress* point of view, although it should be possible to be somewhat more scientific about it!

In this connection, a very interesting experiment could be set up to show that elastic buckling occurs when the lateral stiffness becomes zero. At various stages during axial loading of the column the lateral stiffness may be measured by applying a side load at the middle and measuring the lateral deflection. If the first quantity is divided

by the second and plotted against end load, it will be evident that the lateral stiffness approaches zero as the applied load approaches the Euler buckling load. This method has been found very useful in predicting the critical buckling load of large structures, without carrying the test to actual failure.

The use of the stress-strain diagram in the plastic range can be convincingly demonstrated by employing the *tangent modulus* in the Euler equation, to predict the "short-column" curve. It would be necessary to obtain a compression stress-strain diagram for the material, using a short compact specimen. Other lengths of the same bar would then be tested as columns.

Closely related to the subject of nondimensional curves, previously mentioned, is the application of the principles of dimensional similarity. Although this subject has been highly developed by many authors, some engineers seem to be unaware of the usefulness of the most elementary principles. For example, assume that a test has been conducted to determine the strength of a certain compression panel. This test actually gives the answer for an infinite family of geometrically similar panels, each of which is derived from the tested structure by multiplying all dimensions (including length) by a size factor, n. It is only necessary to multiply test loads by n^2, in determining the strength of any member of the family. For members which fail in bending or torsion, the moments vary as n^3. Stresses stay constant, while cross-sectional areas vary as n^2 and weights vary as n^3.

This simple reasoning may often be used to save many hours of stress analysis or thousands of dollars worth of testing. To check on the possibility of "expanding" an existing structural component for use on a larger airplane, for instance, it is only necessary to determine the size factor, n, and note whether the new applied loads happen to be increased by the factor n^2 and the moments (bending or torsional) by n^3. If they are not, it indicates that a different type of design is necessary. This process can be facilitated by using *structural indexes* or coefficients, such as S/h^2 for shear beams (h is depth of beam; S is shear load); M/D^3 for shells in bending or torsion (D=diameter or other comparable dimension).

It might be advisable to impress the student with the importance of these principles by conducting tests of geometrically similar structures of different size. At the same time it should be made clear that the principles may not apply equally well to dynamic loading conditions such as impact, where size has more than a geometrical effect.

There are many other interesting subjects suitable for laboratory demonstration, but in general these are already well recognized and will therefore be mentioned only briefly. Some of the more important are fatigue, impact, stress concentration, redundant structures, relaxation methods of analysis, and temperature effects. In addition, a few production subjects would help round out the students' structural knowledge. Typical of this class are springback, minimum bend radius, local elongation, and welding (arc, gas, spot, flash, etc.). In fact, the modern structural engineer should be well trained in the principles and applications of physical metallurgy.

Some of the more recent developments in testing equipment and techniques may be of interest. Photoelasticity is, of course, a field in itself and needs no further emphasis. Stresscoat (strain-indicating paint) may be found

useful in developing a better understanding of strain distribution. Large rubber models, inscribed with suitable grids, are most useful in demonstrating many structural phenomena (for example: tension-field webs). Photogrids may be placed on actual test specimens and are widely used in connection with sheet metal forming. It is taken for granted that the resistance type of electrical strain gauge will be demonstrated and described. In fact, the student should be required to construct several such gauges, calibrate them, and use them to measure strains on a structure under load. Advanced courses should include the use of the oscilloscope for dynamic strain measurements, and the oscillograph for recording variable strains. The standard mechanical and optical types of strain gauges should be included in the less advanced courses.

All this sort of work will help put across a fundamental point, which is that most structural analysis is actually *strain* analysis and that stresses cannot be measured directly. This is perhaps one of the most important trends in modern structural analysis and every effort should be made to avoid the easy mistake of lumping stress and strain together, or using one term when the other actually applies. A simple guide to give the student is that stress is usually involved in dealing with equilibrium, while strain is connected with the geometry and continuity of the structure. Because it has been possible to make simplifying assumptions regarding the strain distribution in tension, bending, and torsion, it has become customary to think in terms of stresses. Actually strain comes first. Failure to realize this will make it very difficult to understand and analyze structures such as joints, in which localized conditions are involved. This is, of course, nothing more than an applicant of St. Venant's principle, but it is doubtful whether the far-reaching significance of this principle is clearly recognized by most students.

In discussion and correspondence with educational people one of the most frequent questions concerns the place of aeronautical engineering subjects in the curriculum. In fact, there seems to be some question as to whether aeronautics should form the basis for a school of engineering. It would seem that the answer to this controversial question may be found by examining the evolution of the aircraft industry itself, particularly the engineering department.

Only a few years ago it was possible for an individual to carry most of the responsibility for the design of an entire airplane. In those adolescent days of the industry the greatest problems were aerodynamic; educational attention was therefore centered around aerodynamic theory, performance, and wind tunnel work. Stress analysis was at first not too difficult, as most structures were simple trusses and it was not essential to work to the close margins of safety required today. The mechanical features of yesterday's airplanes were elementary, consisting largely of control cables and simple mechanisms. It was therefore quite possible for an individual to acquire the necessary educational background in all of the subjects involved. After a few years of experience he might be able to design an airplane that would fly reasonably well; in other words, he could rightly call himself an aeronautical engineer. Under these conditions the aeronautical engineering schools which were first established did a great deal to accelerate

the progress of airplane design in this country.

Conditions today are entirely different. Aerodynamic design is highly specialized and is concentrated in a very small percentage of the engineering department. Structural analysis has become much more complicated and exacting, as indicated by the foregoing notes. The mechanical and electrical fields have been greatly expanded by such developments as hydraulic systems, retractable landing gear, wing flaps, cabin pressurization, and high altitude problems. The result is that a modern aeronautical engineering department is actually composed largely of structural engineers, mechanical engineers, and electrical engineers. These are usually further subdivided into specialized fields such as hydraulics, heating and ventilating, radio, structural testing, and production engineering. About the only thing that these groups have in common is that they are all trying to do their job with an absolute minimum of weight, to get their stuff into the same space, and to meet the same flight date.

These are the actual conditions as they exist today in any large airplane factory. The trend is toward even more specialization, as the airplane grows larger and more complicated. Getting back to the subject of structures, we need draftsmen, designers, and stress analysts who really understand structures from the ground up, who can readily visualize the most efficient structure for a given case, and who can also make the necessary compromises for low-cost production. Thorough training in the application of the principles of elasticity, structural theory, and physical metallurgy is more important for such people than the study of aerodynamic stability, wind tunnel corrections, and performance calculations. A few fundamental courses in applied aerodynamics and overall airplane design principles and procedures should be all that is necessary in the way of aeronautical training, for structural engineers.

Paradoxically, it appears that the aeronautical engineering profession has become too big for its own shoes. It would seem that future progress would be greater if more attention were given to broadening the older schools of engineering to include problems connected with airplane design, production, and operation. In this way the airplane industry would secure greater benefits from developments in other industries, while the new problems of aeronautics would stimulate thinking in the older branches of engineering.

RCA Electron Microscopes*

By PERRY C. SMITH

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The electron microscope differs from the optical microscope chiefly in that in it the specimen to be examined is "illuminated" by directing on it a concentrated beam of electrons, instead of light. In passing through the specimen, the electrons are affected in varying degree, according to the density and composition of the various parts of the specimen. Thus, the electron beam emerging from the specimen bears the pattern or "image" of the specimen. This "image" is magnified by as much as 20,000 times by a system of "magnetic lenses" which correspond in function to the optical lenses in a light microscope.

Since the electrons have a much shorter wavelength than light, they can make visible details and particles much smaller than the smallest that can be seen with a light microscope. For this reason, electron micrographs have such good resolution that they may be photographically enlarged 10 or 20 times further, providing a total useful enlargement of 100,000 to 200,000 times the diameter of the original specimen. This compares with 2,000 to 3,000 diameters with the best optical microscopes.

Another advantage of the electron microscope is that the practice of "staining" the specimen, often used in optical microscopy, has not been found necessary up to this time. Many structural details ordinarily blurred by staining can be seen in the unstained specimen in electron microscopy.

It appears from experience to date that specimens from which all surface moisture has first been removed can be subjected to a concentrated electron bombardment in a vacuum without injury to the specimens.

Important new applications of the electron microscope in the field of bacteriology include the study of the effects of disease-inhibiting drugs such as penicillin and sulfanilamide. In such studies, for example, electron micrographs have been made of staphylococcus aureus (a bacterium which causes bloodstream infections) in their normal state and after subjection to the drug.

In the field of biology, the use of the electron microscope is more limited because no satisfactory method has been found to slice sufficiently thin sections for examination. Nevertheless, it has already made some important contributions, including a series of micrographs of sections from the anatomy of the malaria mosquito (Anopheles quadrimaculatus). Among these were sections from the salivary glands, gut, wings, and wing scales

* Presented at the Spring Meeting, Mid-Atlantic Section, S.P.E.E., May 6, 1944, Camden, N. J.

A large, clear micrograph also was obtained of the malarial sporozoite itself. From pictures of this kind, with their wealth of new detail, it is hoped that scientists will be able to work out new methods of controlling and eventually eradicating such diseases.

Experience and knowledge in the field of electron optics, gained by RCA in years of television research, has played an important part in the design and construction of electron microscopes for production on a commercial basis. Today, more than sixty RCA Electron Microscopes are in use, with many more on order. The experience gained with this group of instruments, most of which are located in leading research laboratories, has made it possible to define more accurately the advantages of the electron microscope, the results which may be expected, and the fields in which it will find the greatest application.

The electron microscope consists of five main elements; (1) a vacuum system, including pumps, valves, etc.; (2) an electrical system made up of several power supplies; (3) an electron optical system, which forms the microscope proper; (4) a control system; and (5) a housing.

The new Universal Model of the RCA Electron Microscope represents a complete redesign of the laboratory type instrument which has been in production for the past four years. It incorporates many improvements and simplifications in mechanical and electrical design which make for more convenient operation, more consistent results and greater ease in servicing. The field of application has been broadened and the usefulness increased by including an electron diffraction camera as a built-in unit. Thus, it is now possible to make electron micrographs and electron diffraction patterns of the same specimen in a matter of minutes. The information gained by electron diffraction is of great value in determining the atomic structure of a substance. The electron diffraction unit alone may sometimes be used in identifying unknown substances and in detecting impurities in known materials.

When a photograph is to be taken, slide doors cover the windows. The cable release on the panel operates a shutter exposing the plate. Direct magnification can be varied in forty steps from 100 times to 20,000 times. Resolution is better than 100 Angstrom units—that is, details as small as a quarter of a millionth of an inch can be seen.

The Console Model of the RCA Electron Microscope is an entirely new type of instrument designed to meet the need for a smaller, less expensive unit. It employes the same type of circuit as the larger microscope (including the highly desirable feature of magnetic lenses), is built to the same quality standards, and provides performance of the same order as its bigger brother. It does not however have a diffraction unit, and has only two magnification steps—500 times and 5,000 times.

In the Console Model, the electron optical system is mounted horizontally and the image appears directly on the screen at eye level. The whole equipment, including oil and mechanical pumps and power supply, is mounted in a desk-type console. Access to the pumps and power supply is from the back. Specimens are inserted through a door in the top of the column. Photographs are taken by inserting a 2″ × 2″ slide in the door just beneath the viewing screen.

The Console Model is especially suitable for use in smaller laboratories, in schools, in hospitals, and for process control and material control in factories. Because of its simplicity of operation, it can be operated with a minimum of training. It is particularly well suited for control and analyses operations which have been more or less standardized. It is expected to find widespread use for this purpose in the chemical, metallurgical, textile, food and petroleum industries as well as in the bacteriological field.

Status of Television*

By KENNETH A. CHITTICK

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Television broadcasting was formally introduced to the public at the opening of the New York World's Fair. At that time, television receivers were offered for sale by General Electric, DuMont, RCA and others which incorporated picture tubes producing pictures on 5 inch, 9 inch, 12 inch, and 20 inch screens.

Shortly after, RCA demonstrated large-screen television to a select audience in a New York theater. This picture was projected on a standard motion picture screen by a Schmit optical system consisting of a 36-inch reflecting mirror and correcting lens. The picture was 20 feet in width. In order to produce sufficient light for so large a screen, it was necessary to develop special cathode ray tubes and circuits for operation at 70,000 volts.

The first steps were also taken in the development of television relays to transmit television pictures to distant cities. Both radio relays operating at very high frequencies and coaxial cables were developed and installed for the transmission of these pictures.

The first coaxial cable was laid between New York and Philadelphia by the Bell Telephone Company, and experimental pictures were successfully transmitted.

The introduction and rapid growth of a new industry was not without its problems. The Radio Manufacturer's Association, through their Engineering Committees, had originally formulated a set of engineering standards of transmission which were utilized at the time of introduction of television broadcasting.

The Federal Communications Commission became interested in determining the best set of standards for the industry in order to prevent, insofar as possible, any obsolescence in the television sets sold to the public. The commission issued instructions for a new group of engineering committees to be set up to review the RMA standards then in operation, and to approve or to formulate new standards for the future television industry. This work was practically completed at the opening of the war.

Since the war, all television development has been curtailed. However, development work on allied war equipment has been accelerated, and the knowledge gained through this concentrated effort on new radio circuits can be applied to postwar television techniques. It is expected that postwar television receivers will have brighter pictures, larger screens, both the direct viewing and the projection type and at reasonable cost to the public. It is expected that Schmit optics

* Presented at the Spring Meeting, Mid-Atlantic Section, S.P.E.E., May 6, 1944, Camden, N. J.

using plastic lenses will be utilized in the design of some of these projection receivers.

In the past few months, the Federal Communications Commission has again encouraged a further review of the television standards by engineers of the industry. A Radio Technical Planning Board has been set up consisting of experts representing the entire radio industry, as well as others who are either using or have claims on the radio spectrum. This Radio Technical Planning Board has been instructed to review the recommendations formally prepared by the original engineering committee and to make new recommendations to the FCC on television standards and also on the allocation of frequencies for all radio services.

It is the object of the Radio Technical Planning Board to have all of these questions settled before the end of the war insofar as manpower is available, so that the postwar radio industry may formulate definite plans and be able to introduce television and also expand frequency modulation broadcasting, as soon after the termination of the war as possible.

The first television markets will logically be in the cities where television transmitters have been constructed. Such facilities are now available in New York, where television programs are now broadcast practically every day of the week, Philadelphia, Albany-Schenectady, Chicago, and Los Angeles.

Estimates have been made that within four years after the resumption of television service, approximately thirty-three million people will have access to television broadcasting through the establishment of television networks by either coaxial cable or microwave relay systems.

In ten years, it has been estimated that television service will be available to eighty per cent of all the wired homes in the United States.

At the present time, the Radio Technical Planning Board is reviewing television standards, and although this work is not complete, it might be interesting to review briefly the major proposals.

It is proposed that television be broadcast in the 50–250 megacycle region on channels 6 megacycles wide using single side band transmission. Twenty-six different channels have been indicated for assignment throughout the country.

The largest number of channels will naturally be assigned to the major centers of population. As an example, New York City will have approximately a dozen channels available for television stations.

Television pictures will be broadcast by a system of interlaced scanning utilizing 525 lines and 30 complete pictures every second. This system will reproduce at the television receiver a picture of adequate definition even for a projected picture of the larger size.

Summing up, television is ready today technically, and only awaits the winning of the war for a concentrated effort by engineers to produce television transmitters, receivers, studio equipment, and other associated apparatus necessary for complete operation of a television system.

Properties and Uses of Luminescent Materials*

By LAWRENCE T. WEAGLE

RCA Victor Division, Lancaster, Pa.

In the year 1609, an Italian alchemist Vincenzio Casciarollo, accidentally heated together in his forge a mixture of charcoal and the white mineral barite. As the daylight faded from his crude laboratory, Casciarollo observed a weird blue light emanating from the rocks he had heated.

For over two centuries thereafter, alchemists toyed with these fascinating substances that glowed in the dark. In the middle of the nineteenth century the French chemist Becquerel sought to discover the cause of the light giving properties of phosphors. He failed in this but discovered radio activity. X-rays were discovered by Roentgen when a barium platino cyanide became luminescent under the then unknown radiations.

Interest in luminescent materials then declined somewhat, until, in 1932, electronic engineering gave impetus to further research. Thus, Casciarollo's experiment led to a sequence of events culminating in vastly superior phosphors.

RCA's interest in inorganic luminescent materials, or phosphors, began with the inception of electronic television. It is the phosphors which have made the present development in this art possible. With their aid, science was able, for the first time, to efficiently transform the electron of a radio circuit into light patterns.

Properties of Phosphors

Phosphors are tiny crystals which are able instantaneously to transform invisible radiations such as cathode rays or ultra-violet light into visible light. They can store up or remember information for controllable time intervals of one ten-thousandth of a second to sixteen hours. Those that are able to store up energy and emit it as light after the exciting source is removed are phosphorescent. If they have no afterglow they are fluorescent or, as we say, of short persistence.

A truly fluorescent material emits all its light in less than 1/1,000,000 of a second; one with long phosphorescence will glow for 20 hours. Between these two extremes phosphors can be made with intermediate decay rates.

In the past decade we have synthesized over 9,000 luminescent materials. Although, the majority are, of course, inefficient, many have unusual characteristics.

Phosphors are able to convert electrical power into light more efficiently that any other practical means. Probably more remarkable are the extremes under which a phosphor will function. For example, they will glow for several minutes after an excitation of less than one-millionth of a second's duration.

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The same phosphor will produce visible light from the impact of cathode ray electrons accelerated by 6 volts or 6 million volts. Some are sensitive to an electron beam current smaller than one one-hundred-millionth of an ampere. Under electron bombardment of 70 thousand volts a coating 4 ten-thousandths of an inch in thickness may have a brightness of a million and a half foot lamberts. A well lighted printed page has a brightness of 10 foot lamberts.

Only synthetic luminescent materials which are tailor-made have these qualities. As a matter of fact, ordinary materials such as salt, sugar and glass do luminesce faintly. Actually, of all inorganic materials we have made or examined, we have yet to find one which does not show some luminescence if the proper excitation is supplied. If an absolutely pure material with a perfect crystal structure could be made it would not be luminescent. The problem of making efficient phosphors then is to incorporate, in a very pure base material, controllable amounts of certain desirable impurities such as copper, silver, and manganese. The constituents must then be fired at the proper temperature to produce perfect crystallization except for a necessary slight distortion and irregularity in the crystal lattice.

Chemical Types of Phosphors

Chemically, we divide phosphors into two types, silicates (or oxygen-bearing type) and sulfides. Zinc and cadmium sulfide form an isomorphous series which affords us a complete color range from red to violet. In this series are the principal sulfides which we use in electronic work. If we add silver as the activator impurity to members of the zinc cadmium sulfide family, the phosphors we obtain are fluorescent. If we add copper instead of silver, they become phosphorescent. The color changes from violet to red as we increase the per cent of cadmium sulfide.

Examples of the oxygen bearing types are silicates, tungstates, and borates of the alkaline earths, or zinc and beryllium. The most efficient silicates phosphor is willemite or zinc ortho silicate.

The most characteristic physical difference between the two groups is their selective response to different wavelengths of ultra-violet excitation. Silicates respond only to short U.V. radiations from a low pressure mercury arc. Sulfides are excited best by wavelengths around 3600Å.

The activator, although present in very small amounts, produces a remarkable change in the luminescent properties of the base constituent. If we add one per cent of manganese, the emission color is changed from a blue to a green and there is a corresponding increase in luminous efficiency of several hundred per cent. Likewise, one per cent of manganese added to zinc germanate will shift the emission spectra from the ultra-violet to a green yellow with a peak at 5400Å.

If we add one part in ten thousand of silver to zinc sulfide, the emission peak is shifted 500Å toward the blue. However, if, instead of silver, we add copper, the emission color changes to green.

Phosphors, when properly made, are remarkably stable; however, if you heat them to a high enough temperature, luminescence is reduced to zero and is replaced by incandescence. On cooling, luminescence reappears. If, however, the proper precautions are not taken to assure that contaminating

metals are absent, the luminescent property will be permanently destroyed. The manufacture of phosphors must be carried out under scrupulously clean conditions. For example, contamination by one part in ten million of nickel or iron will decrease the luminescent efficiency of the phosphor 75 per cent. For this reason, we prepare phosphors in an air-conditioned laboratory and factory.

Uses of Luminescent Materials

The first phosphor used by RCA in the television screen was green willemite. People soon became tired of seeing a green hippopotamus, a green mayor of New York, a green Hedy Lamarr. They demanded a more pleasing color, preferably white. Television white is actually not one phosphor but a mixture of blue and yellow phosphors.

The coating in fluorescent lamps is composed of blue magnesium tungstate and yellow zinc beryllium silicate. Fluorescent lamps have efficiencies 2 to 4 times as great as incandescent lights and are saving this country vast amounts of electric power a year. For illumination purposes these tiny crystals may be incorporated into paints, plastics and vitreous enamels.

For wartime uses, phosphors are ideal for blackout illumination on power switches and exit signs. The Maritime Commission specifies that all liberty ships of over 3,000 tons must have 4-inch-wide phosphorescent tape marking all passageways.

Phosphor plastics find use in radio control knobs on test equipment which must be operated in the dark. Luminescent paints find use on aircraft instrument dials and advertising and display signs. Luminescent walls and murals in the home of the future are not beyond the realm of possibility.

In conclusion, I believe we can say that phosphors have added immeasurably to our health and happiness. They have indirectly given us radium and X-rays. They are on the fluoroscope screen which the doctor uses to set a broken bone. They are helping us tremendously in many ways to win victory over our enemies. They have made television practical and the electron microscope possible. With their aid you now have projection television and will some day have color television.

RCA and Industrial Electronics*

By FRED W. WENTKER

Manager, Electronic Apparatus Section, RCA Victor Division, Camden, N. J.

Few subjects are more intriguing than the applications of electronics in industry, and few are more inexhaustible. Time, however, permits but the briefest examination of some aspects of this field.

One important application of electronics in industry is the modern plant-wide Sound Communications System which is being used for paging, for control of men and material, and, in ways which build employee morale. Included in the latter is the widespread use of music programs to relieve fatigue.

RCA's leadership in this field is attested by the numerous installations in leading manufacturing plants, including industry leaders such as Botany Mills, Bethlehem Steel, Alcoa, and Curtiss-Wright.

Another important application of electronics in industry is the Sound Motion Picture Projector. Now it is rendering an enormous service in training and entertaining our nation's personnel under arms. At war's end, it will take its rightful place in industrial training and entertainment programs. A typical unit is the rugged and dependable RCA 16mm. projector which is serving wherever our Armies are stationed—whether in the Tropics or the Polar Regions.

What promises to be one of the most important of industrial electronic applications is the use of high-frequency power from electron-tube oscillators in industrial heat processes.

I am referring, for example, to the use of electronic power through induction heating methods for soldering and brazing, for case-hardening, for annealing, for tin-plating (reflowing), and for welding (principally small parts).

I am also referring to the more recently developed applications of electronic power in the heating of non-conductors or dielectrics. Commercial applications include wood gluing, plastics preheating as an aid to faster and better modling, drying rayon yarn, heating rayon cord to balance twist stresses, heating explosive material for extrusion, and bonding thermoplastic sheet materials. Beyond these are many potential applications which haven't yet been developed to the commercial stage.

In all of these applications, electronic power is contributing to a cheaper product or a more satisfactory product than conventional processes permit. This results primarily from greater speed and better control. Our war production is deriving real benefits from these applications.

RCA commercial industrial oscillators are available today (to war plants only, of course; and to these, only on

* Presented at the Spring Meeting, Mid-Atlantic Section, S.P.E.E., May 6, 1944, Camden, N. J.

comparatively high priority ratings) in a limited range of sizes extending all the way from 100 watts to 150 kilowatts output. Operating frequencies range from approximately 400 kilocycles to 200 megacycles.

Electronic power generators must be built to industrial standards with features that fit them into industrial plant conditions. Designs must contemplate conditions such as high operating temperatures, mobility, excessive humidity, excessive dirt in atmosphere, operation by reatively unskilled personnel, and convenience in operation. This calls for ingenuity and imagination in design as well as an understanding of customer needs. Solutions to the problems involve a high order of mechanical engineering ability as well as electronic engineering of the front rank. The incorporation of all these elements is exemplified by the new RCA Model 2-B Electronic Power Generator.

In closing, I shall touch upon applications of optical films, whose operation is based on light interference phenomena, and which are used principally to make optical lenses and devices more efficient. Electronic apparatus is employed in the application of the film material.

The best known types of processes, are those which create so-called nonglare or non-reflecting surfaces. A multiple element lens so treated transmits appreciably more light (3–4 per cent per treated surface), and provides a substantial improvement in image contrast.

RCA has at Indianapolis modern facilities for processing lenses for manufacturers and assemblers of optical devices. Hundreds of thousands of binoculars and telescopes in war service today are proving more useful and efficient by virtue of the treatment given their lenses at our plant.

Optical films of a more complex type, known as dichroic reflectors, divide light on a color selective basis without any appreciable absorption. A plate treated with such a film may appear to be yellow until backed up by a white card, and then show up as blue. These films have application for special optical problems and instruments.

Besides being a leading processor of optical parts, RCA also is a leader in the delevolpment of new and advanced methods and equipment for creating all types of optical films. Wartime applications, developments and experiences related to optical films will create a demand for civilian applications to camera, microscope, and projection lenses, and to spectacles and picture glasses, to mention but a few. This represents an additional example of how electronics can help to provide better products for all of us.

The Castigliano Theorem and the Requirement that Displacements be Linear Functions of the Loads

By H. C. PERKINS

Assistant Professor of Mechanics of Engineering, Cornell University

The Castigliano Theorem, which expresses displacements as partial derivatives of the strain energy, implies linear relations between loads and displacements. Thus S. Timoshenko in his "Strength of Materials" text* makes it clear that in the case of a single load the Castigliano Theorem does not hold when the displacement is not proportional to the load, and ends the discussion with a statement that "analogous results are obtained in all cases in which the displacements are not proportional to the loads."

It is an interesting exercise in applied mathematics to consider the general case of any number of loads on an elastic structure and show that the Castigliano Theorem is not valid unless the displacements are linear functions of the loads.

As a preliminary exercise to illustrate the argument, consider the case treated by Professor Timoshenko; *i.e.* a simply stiff structure with statically determinate support, subjected to one load of given location and direction but variable magnitude H.

Assuming that: (1) the working displacement h of the load H (*i.e.* the component in the direction of H of the displacement of the application point of H) is uniquely determined by that load; (2) the equations of statics have been used to express all reactions and internal stresses in terms of H; and (3) these expressions have been used to formulate the strain energy in terms of H and constants; it follows that the differential displacement may be expressed by the formula

$$dh = \frac{dh}{dH}\,dH, \tag{1}$$

and a similar formula for the differential strain energy is

$$dU = \frac{dU}{dH}\,dH. \tag{2}$$

By definition the strain energy is equal to the work done by the load, so

$$dU = H\,dh. \tag{3}$$

Substituting from equation (1) in equation (3)

$$dU = H\,\frac{dh}{dH}\,dH. \tag{4}$$

Comparing equations (2) and (4) and noting that by Castigliano's Theorem

$$\frac{dU}{dH} = h, \tag{5}$$

* D. Van Nostrand, New York, 1930, Art. 74, p. 347; or 1940, Art. 72, p. 339.

it follows that

$$\frac{dU}{dH} = H\frac{dh}{dH}$$

and

$$h = H\frac{dh}{dH}. \tag{6}$$

To show that h is linear in H, differentiate equation (6) with respect to H. (The right side is a product.)

$$\frac{dh}{dH} = \frac{dh}{dH} + H\frac{d^2h}{dH^2} \tag{7}$$

or

$$H\frac{d^2h}{dH^2} = 0, \tag{8}$$

which can be true for all values of H only if

$$\frac{d^2h}{dH^2} = 0, \tag{9}$$

which proves that the working displacement of a single load must be a linear function of the load. Since equations (1), (2), (3), (4) are valid for relations other than linear, it follows that the linear restriction is introduced by the Castigliano Theorem.

In case there are several loads $H, \cdots Q, \cdots$ the argument is a little more involved but follows the same line as when there is but one load. Thus: assuming that the strain energy U and the working displacements $h, \cdots q, \cdots$ of the loads are uniquely determined by those loads, a formula for the differential strain energy is

$$dU = \frac{\partial U}{\partial H}dH + \cdots + \frac{\partial U}{\partial Q}dQ + \cdots, \tag{10}$$

and there are similar formulas for differential displacements such as

$$dq = \frac{\partial q}{\partial H}dH + \cdots + \frac{\partial q}{\partial Q}dQ + \cdots. \tag{11}$$

The differential strain energy in terms of work done by the loads is

$$dU = Hdh + \cdots + Qdq + \cdots. \tag{12}$$

Substituting, in equation (12), the expression for dq from equation (11) and similar expressions for other differential displacements $dh, \cdots$,

$$dU = H\left(\frac{\partial h}{\partial H}dH + \cdots + \frac{\partial h}{\partial Q}dQ + \cdots\right) + \cdots + Q\left(\frac{\partial q}{\partial H}dH + \cdots + \frac{\partial q}{\partial Q}dQ + \cdots\right) + \cdots. \tag{13}$$

Comparing coefficients of dH in equations (10) and (13) and noting that by the Castigliano Theorem

$$\frac{\partial H}{\partial H} = h \tag{14}$$

it follows that

$$h = H\frac{\partial h}{\partial H} + \cdots + Q\frac{\partial q}{\partial H} + \cdots. \tag{15}$$

Differentiating equation (15) (Q is independent of H, etc.)

$$\frac{\partial h}{\partial H} = \frac{\partial h}{\partial H} + H\frac{\partial^2 h}{\partial H^2} + \cdots + Q\frac{\partial^2 q}{\partial H^2} + \cdots \tag{16}$$

or

$$H\frac{\partial^2 h}{\partial H^2} + \cdots + Q\frac{\partial^2 q}{\partial H^2} + \cdots = 0, \tag{17}$$

which can be true for all values of $H, \cdots Q, \cdots$ only if

$$\frac{\partial^2 h}{\partial H^2} = 0, \quad \cdots \frac{\partial^2 q}{\partial H^2} = 0, \tag{18}$$

with similar results for other variables, such as Q.

The cross derivatives such as $\frac{\partial^2 h}{\partial H \partial Q}$ also vanish. Thus the strain energy may be differentiated with respect to both H and Q, the result being independent of the order of differentiation.

$$\frac{\partial}{\partial Q}\left(\frac{\partial U}{\partial H}\right) = \frac{\partial}{\partial H}\left(\frac{\partial U}{\partial Q}\right). \tag{19}$$

But by the Castigliano Theorem equation (19) may also be written

$$\frac{\partial}{\partial Q}(h) = \frac{\partial}{\partial H}(q). \tag{20}$$

Differentiating equation (20) with respect to H

$$\frac{\partial^2 h}{\partial H \partial Q} = \frac{\partial^2 q}{\partial H^2}, \tag{21}$$

which vanishes by equation (18). In similar manner all other cross derivatives vanish.

Since each second derivative of each displacement vanishes, it follows that the displacements are linear functions of the loads, and since equations (10), (11), (12) are valid for functions other than linear, it follows that the restriction that the displacements must be linear functions of the loads is imposed by the Castigliano Theorem.

Coöperative Education in Colleges and Universities

By LEO F. SMITH

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Introduction

The war has brought about many changes in coöperative programs and it is probable that when peace again returns some of the institutions which had such programs will have discontinued these and other institutions, which had previously not been adherents of this plan, will initiate coöperative work as an integral part of the student's education. Because of this it is believed that a report on the status of coöperative education in colleges and universities as of the school year 1940–41 will provide an interesting basis for the study of future programs. This summary is a portion of a larger study made to determine various features concerning coöperative work programs in all higher educational institutions. The entire study was undertaken at the invitation of the Commission on Terminal Education of the American Association of Junior Colleges and the General Education Board and has already been reported elsewhere.*

Institutions Offering Coöperative Programs

A study of Fig. 1 reveals that 39 colleges and universities have had coöperative curriculums at some time since the first one was started at the University of Cincinnati in 1906. Ten of these programs had been discontinued leaving a total of twenty-nine, twelve were in publicly controlled and seventeen in privately controlled institutions.

There appear to have been three phases in the growth of the coöperative plan. The first of these was characterized by a steady but slow growth which was brought to a halt by World War I. Following the war there was a rapid increase in the number of programs which came to a halt about 1930. Few programs were organized during the depression, but starting in 1936 there was a period of accelerated growth which was halted by World War II.

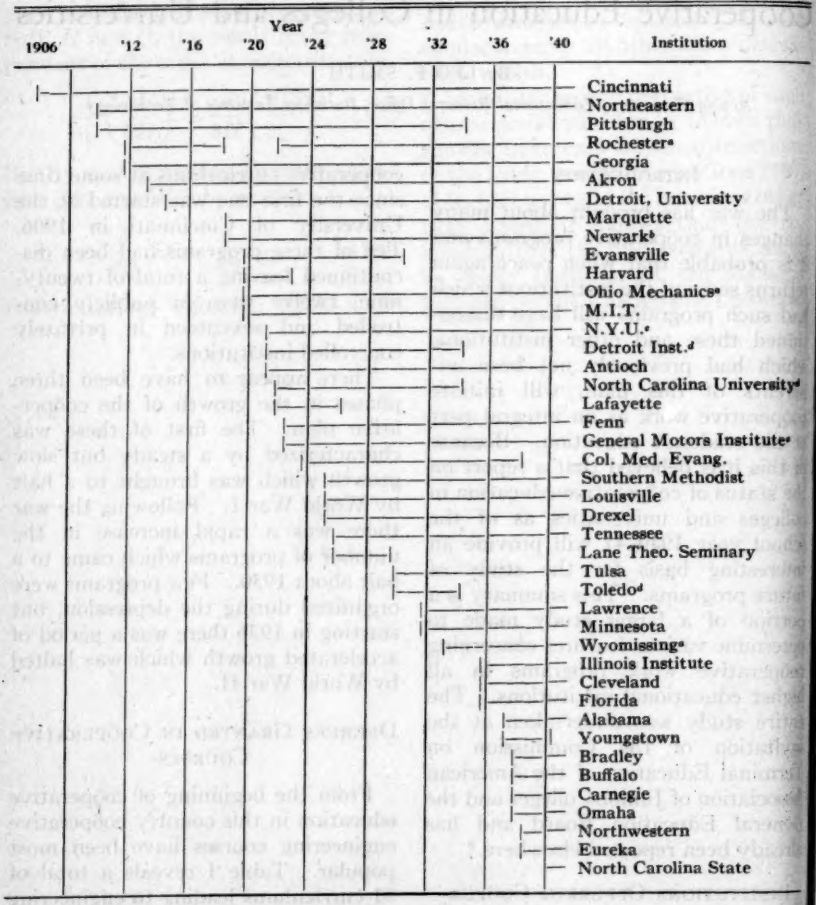
Degrees Granted in Coöperative Courses

From the beginning of coöperative education in this country coöperative engineering courses have been most popular. Table I reveals a total of 91 curriculums leading to engineering degrees and a total of only 22 curriculums leading to other types of degrees. Of the engineering curriculums, the four most popular are mechanical (18), electrical (17), chemical (15) and civil (15), for a total of 65. All other types of engineering programs combined add up to 26.

*Leo F. Smith, "Coöperative Work Programs in Higher Institutions in the United States: Present Status, Trends and Implications," Unpublished Ph.D. dissertation, University of Chicago, 1943, pp. 208.

FIGURE I

YEAR OF INTRODUCTION AND ABANDONMENT OF COÖPERATIVE WORK PROGRAMS IN COLLEGES, UNIVERSITIES, AND TECHNICAL INSTITUTES AS OF 1940–41



[a] Non-degree granting technical institute.

[b] Newark discontinued regular coöperative program but offers some work experience for Honor students.

[c] N.Y.U. discontinued coöperative engineering courses sometime during the depression but still offers coöperative retailing courses.

[d] Program discontinued sometime during depression.

[e] Operates at the college level but does not grant degrees—program is designed to train men definitely for the Divisions of the General Motors Corporation.

TABLE I

Degrees Granted in Coöperative Courses by Colleges and Universities Carrying on Coöperative Work Programs

Institution	Engineering Degrees																			Other Degrees							
	Aeronautical	Architectural	Biological	Biophysics	Ceramic	Chemical	City Planning	Civil	Commercial	Electrical	Engineering	General	Geological	Industrial	Management	Marine Transp'n	Mechanical	Metallurgical	Petroleum	Textile	Bach. of Art	B. of Bus. Ad.	M.S. in Ret.	Bach. of Sc.	B.S. in Commerce	B.S. in Home Ec.	Arch. and App. Art	B.S. in Bus. Ad.
Akron[a]	.	.	.	.	.	.	.	x	.	x	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Alabama[a]	.	.	.	.	.	x	.	x	.	x	.	.	.	x	.	.	x	.	.	x	.	.	.	.	.	.	.	.
Antioch	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	x	.	.	.	.
Bradley[b]	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Buffalo	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.	.	.	.	.	.
Carnegie[a]	.	.	.	.	.	x	.	.	.	x	.	.	.	.	x	.	x	x	.	.	.	.	.	.	.	.	.	.
Cincinnati	x	.	.	.	.	x	.	x	x	x	.	.	x	.	.	.	x	.	.	.	.	x	.	x	.	.	x	.
Cleveland	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.	.	.	.	.	.
Detroit[a]	x	x	.	.	.	x	.	x	.	x	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Drexel[b]	.	.	.	.	.	x	.	x	.	x	.	.	.	.	.	.	x	.	.	.	.	.	.	.	x	x	.	x
Eureka[a]	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	x	.	.	.	.
Fenn[b]	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	x	x	.	x	.	.	.	.
Florida[a]	.	.	.	.	.	x	.	x	.	x	.	.	.	x	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Georgia[b]	.	.	.	.	.	x	.	x	.	x	.	.	.	.	.	.	x	.	.	x	.	.	.	.	.	.	.	.
Illinois[b]	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Lawrence[b]	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Louisville[b]	.	.	.	.	.	x	.	x	.	x	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Marquette[a]	.	.	.	.	.	x	.	x	.	x	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
M. I. T.[c]	.	.	x	x	.	x	x	.	.	x	.	.	.	.	.	x	x	.	.	.	.	.	.	.	.	.	.	.
Minnesota	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.
New York U.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.
Newark[b]	.	.	.	.	.	x	.	x	.	x	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
N. Carolina	x	x	.	.	x	x	.	x	.	x	.	x	x	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Northeastern[b]	.	.	.	.	.	x	.	x	.	x	.	.	.	x	.	.	x	.	.	.	.	.	.	.	.	.	.	x
Northwestern[b]	.	.	.	.	.	x	.	x	.	x	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Omaha	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	x
Southern	.	.	.	.	.	.	.	x	.	x	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Tennessee[b]	.	.	.	.	.	x	.	x	.	x	.	.	.	x	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Tulsa[b]	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.	.	.	.

[a] Bachelor of Engineering degrees are granted in the various areas such as Bach. of Civil Eng., Bach. of Chem. Eng., etc.

[b] Bachelor of Science in Engineering degrees are granted in the various areas.

[c] M. I. T. grants both the B.S. and M.S. in Me. and Elec. Engineering to graduates of these five-year coöperative courses. Courses requiring practice periods prior to graduation are also offered in Biol. Eng., City Planning, Biophysics, and Marine Transportation. These courses lead to the B.S. in the respective fields.

TABLE II

Length of Coöperative Courses, Years Coöperative Work Is Given and Period of Alternation as of 1940–41

Institution	Length of Course in Yrs.	Years Coöperative Work is Given	Period of Alternation
Akron	5	3–4 and ½ of 5	9 weeks
Alabama	5	1–2–3–4–5	3 months
Antioch[a]	5 or 6	2–3–4–5 or 1–2–3–4–5	10 weeks
Bradley	5	2–3–4–5	1 semester
Buffalo	5	1–2–3–4–5	4 months
Carnegie	5	1–2–3–4	Summer vacations and sem. in 3rd and 4th yr.
Cincinnati	5	3rd term Fr. yr. to 2nd half Sr. yr.	8 weeks
Cleveland	5	1–2–3–4–5	6 months
Detroit	5	3–4–5	4 weeks
Drexel	5	2–3–4–5	3 months
Eureka	5	1–2–3–4–5	8 weeks
Fenn	5	2–3–4–5	3 months
Florida	6	1–2–3–4–5–6	1 semester
General Motors[e]	4	1–2–3–4	8 weeks
Georgia	5	1–2–3–4 and ½ of 5	3 months
Illinois	5	2–3–4–5	8 weeks
Lawrence	4	1–2–3–4	12 weeks
Louisville	4	2–3	3 months
Marquette	5	3–4–5	4 weeks
M.I.T.[b]	5	3–4–5	4 months
Minnesota	4	4	Winter term Sr. yr.
N.Y.U.[c]	5	5	Afternoons for 1 term
Newark	4	Summer between 2nd and 3rd or 3rd and 4th yr.	Summer vacation
N. Carolina State	5	2–3–4	6 months
Northeastern	5	2–3–4–5	10 weeks
Northwestern	5	2–3–4–5	3 months
Ohio Mechanics[d]	2	1–2	4 weeks
Omaha	5	1–2–3–4	6 months
Rochester[d]	3	1–2–3	4 weeks
Southern Methodist	5	2–3–4–5	6 weeks
Tennessee	5	2–3–4–5	3 months
Tulsa	4	4	8 weeks
Wyomissing[d]	2½	1–2	4 weeks

[a] If coöperative work is elected during first year, six are required to complete course.

[b] For the Mech. Eng. and Elec. Eng. programs. The Biological, Biophysics, Chemical, City Planning and Marine Transportation utilize somewhat different plans.

[c] Retailing coöperative course for graduate students.

[d] Non-degree granting technical institute.

[e] Operates at the college level but does not grant degrees—program is designed to train men definitely for the Divisions of the General Motors Corporation.

Length of Courses and Period of Alternation

Coöperative courses in colleges and universities vary in length from four to six years, with the majority five. Table II indicates the length of coöperative courses in years, the years in which this work is offered and the period of alternation. From this table it may be noted that in five institutions the program was four years in length; in twenty-two it was five; in one it was six; and in one it was either five or six depending on whether a full-time or coöperative schedule was elected during the first year.

The majority of the coöperative

TABLE III

Enrolment in Coöperative Courses in Colleges and Universities for the School Year 1925–26 and 1940–41

Institution	Coöperative Enrolment	
	1925–26[a]	1940–41
Akron	146	95
Alabama	....	350
Antioch[b]	....	536
Bradley	....	40
Buffalo	....	65
Carnegie	....	30
Cincinnati	1,144	1,900
Cleveland	....	350
Detroit	400	732
Drexel	498	1,400
Eureka	....	5
Fenn[b]	....	800
Florida	....	47
Georgia	330	728
Illinois	....	400
Lawrence	....	175
Louisville	58	325
Marquette	447	613
M. I. T.	274	261
Minnesota	....	Limited number
New York University	111	Limited number
Newark	175	Optional for upper 30 per cent of Juniors and Seniors
North Carolina	....	23
Northeastern	1,032	2,000
Northwestern	....	270
Omaha	....	12
Southern Methodist	95	117
Tennessee	....	250
Tulsa	....	35
Total	4,710	11,559

[a] Data from "A Study of the Coöperative Method of Engineering Education," p. 8. Bulletin No. 12, SPEE, 1927.

[b] Program in operation but enrolment figures not available for 1925–26.

engineering courses require full-time college attendance during the freshman year and the work experiences are made available during the second, third, fourth and fifth years. There are, however, variations of this pattern as is evidenced in Table II.

Considerable thought has been given to the optimum length of the school and work programs and there is still considerable difference of opinion concerning this material. At present the period of alternation varies from four weeks to six months in the engineering curriculums with the quarter or three month period being the most popular. Eighteen institutions utilize a period between six weeks and four months in length while eight use the quarter plan of either twelve weeks or three months duration.

Enrollment in Coöperative Curriculums

On Table III is shown the enrollment in coöperative curriculums for those institutions which had these programs in both 1925–26 and 1940–41. In addition to the 4,710 students shown the enrollments in institutions which later discontinued their programs were as follows: University of Pittsburgh (469), University of North Carolina (188), Evansville (95), and Detroit Institute of Technology (88). Antioch College, Fenn College and the College of Medical Evangelists were the only other institutions of higher learning carrying on coöperative work at this time and, although no figures are available from these institutions, it seems probable that the number of coöperative students enrolled in these three institutions combined did not exceed 800. Thus, in 1925–26 the total number of cooperative students in higher institutions was approximately 6,350.

The total number of coöperative students reported in 1940–41 is 11,559, but this does not include those enrolled at Minnesota, New York University and Newark. As the programs at these institutions are relatively small, it is probable that not more than 12,000 students were participating in some type of coöperative work during the school year 1940–41.

The Coördination of the Work of the Physics, Mathematics, and Electrical Engineering Staffs in the Formulation of Communications and Electronics Curricula, Including Ultrahigh-Frequency Techniques*

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Adequate electrical communications curricula always have been more deeply concerned with theoretical analysis than have those of other branches of electrical engineering, since the understanding of electronic phenomena and network behavior so essential to the development of the communications picture requires a closer and a more thorough acquaintance with the mathematical and physical sciences. Postwar curricula in electrical communications and in the many kindred fields in which its techniques find fruitful application must be even more thorough and strong in an underlying theoretical continuity in order to be consistent with the marked rise in level of attainment reached through the present concentration of research effort. This need for increased strength in certain branches of mathematics and physics is already making itself felt in the regular and specialized programs which are currently carried on for the training of personnel needed in the services and in the research laboratories. The need in most cases is being met only partially, and in ways which are temporary expedients rather than adequate solutions. It is necessary, therefore, that we take a longer-range view of this situation with the object of arriving at a clearer picture of how an adequate plan may be fitted into the existing educational picture with a minimum of painful alterations.

Lest, by the last remark, the otherwise apprehensive conservatist be lulled into a feeling that nothing painful is being contemplated, I hasten to remind you that no progress or growth engendered by urgent need and motivated by those of us who are more readily stimulated by the thoughts of embarking upon uncharted ground, is wholly unaccompanied by pain of some sort. At least we must expect that the entire existing curriculum, not merely certain parts of it, will in some measure feel the effects of the necessary alterations. To be well done the job must be thorough, and one must not let the possibility of much added work deter one from making a decision which has only the best interests of the larger plan at heart.

*Presented at the 52nd annual meeting, S.P.E.E. (Electrical Engineering-Physics), Cincinnati, Ohio, June 22–25, 1944.

The subjects essential to the curriculum visualized here are mathematics, physics, and electrical engineering principles. To do the job well it is vital that the staffs of the three departments involved coöperate closely. Failure to do so will spell failure in this as well as in all other plans for the participation of the colleges in the altered postwar picture.

Beyond the usual differential and integral calculus, and some differential equations, the desirable mathematical requirements are:

(a) Theory of functions of a complex variable.
(b) Potential theory and boundary-value problems (including some discussion of cylinder functions and spherical harmonics).
(c) Vector analysis (including a discussion of the wave equation).
(d) Fourier series and integrals.
(e) Advanced algebra.

The physics of the first two years should comprise the usual mechanics, heat, electricity, and optics, including a derivation of the field equations of Maxwell, a discussion of boundary conditions, and a pretty thorough consideration of the essential processes of analysis used in dealing with physical and geometrical optics. The additional work in physics should include:

(a) Theromodynamics, statistical mechanics, and kinetic theory.
(b) Electronics.
(c) Acoustics (including the dynamics of vibrating systems).

The electrical engineering principles which are particularly pertinent are:

(a) Basic circuit theory.
(b) Fourier analysis and its use in characterizing transient in terms of sinusoidal steady-state behavior.
(c) An introduction to network synthesis.
(d) Vacuum tube circuit theory (including multivibrator and sweep circuits, UHF generators and systems).
(e) Transmission lines, wave guides, and antennas.
(f) Associated laboratory work.

From this enumeration of essentials it appears that an adequate curriculum specializing in the field of communications and electronics (including UHF) requires more time than is available—unless revisions are made all along the line and down the line, perhaps even to the high school or precollege level. So far as the mathematics is concerned it is essential that geometry, trigonometry, and some analytical geometry be entrances requirements so that the college work can get started immediately with differential calculus. Such has been the situation at M.I.T. for years, and there is no sound reason why other technical colleges who wish to stay abreast of the times cannot do the same.

If a youngster wants to get into engineering work he should anticipate this fact when planning his high school program. This the colleges have a right to expect. If the entrance requirements are not met, the student either spends a summer meeting them or he doesn't enter. The only way that the technical colleges can ultimately keep abreast of things with a fixed four-year curriculum is to push some of the earlier work down into the secondary school curriculum. These schools will have to absorb some of the burden and it is perfectly sensible that they should. They may in some instances have to vivify their

teaching staff to do this and perhaps even pay some decent salaries in order to attract the necessary talent.

By this expedient alone, however, the accomplishment of the task outlined above is only begun. In order to achieve the desired end two additional steps of major importance must be taken. One of these consists essentially of a revamping or streamlining of the entire teaching program and the other, which is dependent in large measure upon the success of the first, is concerned with the establishment throughout the junior year of an additional full course in mathematics and one in physics.

The process referred to as streamlining begins with a complete and detailed inventory and a critical examination of the items thus brought to light alongside of those which the new curriculum proposes as essential material, with the object of giving each item in the combined list a priority rating based solely upon the worth of that item in furthering the desired program. I can think of a number of items now enjoying a prominent position on the agenda which this process (if honestly and fearlessly carried out) will relegate to a rather obscure level. (The part about honesty and fearlessness refers primarily to doing what is best for the program regardless of whose toes are stepped upon in the process, even if it be those belonging to somebody's chief.) In the way of material which, in competition with the "must" items, may be likely to receive a lower priority rating I have in mind not merely some obsolete pieces of electrical machinery but even such things as a large portion of the material usually included in a course on differential equations. The portion which is really extensively used in the subsequent dependent work is actually a small fraction of the total. This small portion is concerned with the subject of linear differential equations with constant coefficients. The rest is all good material too, but that is not the point. Vector analysis, for example, is also good material and in addition it is really needed and used later on in the curriculum.

I do not propose that material receiving a lower priority rating should necessarily be dropped entirely, but I do propose that the time spent discussing such material may be appreciably cut. To use the subject of differential equations as an example again, it is conceivable that the portion concerned with linear equations with constant coefficients could adequately be dealt with in about four or five lectures. Two additional lectures could then be spent presenting a number of additional types of equations that might be encountered, pointing out the kinds of physical problems in which they arise and providing the students with references which discuss methods of solution. In this way the student becomes acquainted with the commoner types of differential equations, how and where they arise, how to recognize the type, and where to find a method of solution. All of the low-priority material that nevertheless has salvage value may be dealt with in this manner.

A careful selection of detailed items must, of course, also be made in connection with the various topics enumerated above. For example, in connection with the theory of functions of a complex variable the emphasis should be placed upon such things as conformal mapping, Cauchy's integral formula, series expansion, and complex integration. Numerous collateral items which form the setting for these major ones can be dealt with somewhat after

the fashion of the low-priority procedure. This method actually gives the student a better over-all picture of the subject than one which weights all items alike.

The process of streamlining should not be confused with a kind of superficial treatment sometimes found in engineering textbooks in which, allegedly for lack of space, the presentation is often inaccurate, incomplete, and misleading. Brevity does not need to be accompanied by any of these faults. A skillfully executed summary can have depth as well as breadth. It takes no more words to make an accurate statement than it does to make one whose meaning is obscure or misleading. Completeness likewise, by no means necessitates longwindedness.

The mathematics department must, of course, be encouraged to emphasize the physical or geometrical aspects of the various subjects discussed. To the engineer, mathematics is merely a tool, the properties of which are best understood when the appropriate physical or geometrical environment is simultaneously considered. Vector analysis, for example, is a tool for describing the properties of physical fields. The pertinent operators have simple and easily visualized physical interpretations which the presentation should place in the foreground. The finer points involved in rigorous proofs then have a chance to be understood. Otherwise the whole performance becomes a waste of time.

Another way of getting the mathematics into the curriculum is to have the physics or electrical engineering staff teach it along with the applications. This method I do not favor, primarily because it seriously interrupts the continuity of the discussion pertaining to the physical problem in which the mathematical tool is to be used. In order to keep this interruption as short as possible the mathematical item is usually presented as an isolated fragment. Mathematics taught in this way leaves the student with a collection of apparently unrelated parts which he cannot assemble into a unified subject. Moreover, the parts are apt to be misinterpreted since the physics or engineering instructor only in rare instances is sufficiently informed or interested in the purely mathematical side of the picture to be able to give a brief, yet accurate and complete presentation. The sort of slipshod, fragmentary presentations of mathematical principles frequently indulged in by physics and engineering instructors does an amount of damage that is appreciated only by the student himself in later years. It is much better to leave the major presentation of mathematical principles to one who specializes in this field.

Considering the program at large, it is false to assume that any conservation of time results from mixing mathematics, physics, and engineering into an inhomogeneous mass and administering the conglomerate dose in a single operation. Proponents of this method claim that the engineering student understands mathematics only when it is properly mixed with a sauce made from parts of the physical problem, in which it is to be used, while mathematics in its pure state has a formality about it that precludes the receptive attitude essential to understanding. This argument, however, brings us back to the question of how mathematics should be taught.

Mathematics in its pure state is a thing which even the great minds who invented it arrived at only after many successive stages of distillation and re-

finement. It is a thing which can be appreciated only in retrospect, as any honest mathematician is himself ready to admit. Mathematics textbooks which are written in a highly formal manner are written by individuals who have no real desire to be helpful to mankind. Such books are merely a documentation of achievement—a snobbish exhibition of skill. This sort of attitude has no place in the classroom. The teaching of mathematics should begin with a discussion of the physical or geometrical problem in which the pertinent relations have their origin and whereby the successful manipulative operations are suggested. The broad problem, outlined in crude form, may then be put through successive stages of refinement until it is ultimately reduced to its abstract essentials. Thus rigor and completeness may be achieved without loss of clarity or interest. The procedure, moreover, is distinctly different from that which characterizes the mixture of engineering, physics, and mathematics referred to above.

With regard to the participation of the physics staff in the contemplated program, it is again essential to note that this group has clearly defined responsibilities which should not be assumed by the staffs of either the electrical or the mathematics departments. Electronics, including theories of emission, ionization, gaseous conduction, electron ballistics, photoelectricity, etc., is more appropriately taken care of by the physics staff, for these are matters that pertain more specifically to theoretical physics. Practical applications can and should be discussed in engineering subjects (either concurrently or later), but the theoretical foundation should be laid by the physics teacher just as the basic mathematics should be taught first by the mathematics teacher.

Of the various proposals made here, the one which undoubtedly will involve the greatest conflict of opinions is that having to do with the rating of all items on the educational agenda, the relegating of some to rather obscure levels, and the complete exclusion of others. The most difficult part of the program from the standpoint of its execution is probably that of salvaging material having a moderate priority rating. In some instances this problem may take the form of a complete remodeling job. An example might be furnished by the subject of electrical machinery. From the standpoint of the program envisioned here, the existing methods of dealing with the subject of electrical machinery are hoplessly out of step with what is needed.

The communications and electronics engineer needs to know what the external characteristics of many different types of a-c and d-c machines are and why these make the specific types adaptable for certain services. He should know how to select machines to meet the needs of a given power-supply system. Various methods of obtaining dc and ac and vice versa, should be discussed; the frequency should not be confined to 60 cps nor should the d-c voltage be exclusively 110 or 220 volts. His knowledge of why a machine has certain characteristics may be confined to the barest essentials. There certainly is no need for lengthy considerations of the various detailed methods for calculating the effect of armature reaction, etc. Consideration of d-c and a-c rotating machinery and transformers could thus be handled in a single one-term subject plus an appropriate laboratory. In contrast to the situation commonly

prevailing at present, the result would be both interesting and useful to the student.

Difficulties likely to be encountered in putting into effect a proposal of this sort should be expected in dealing with the staff, not with the students. A typical example will be the chap who has been teaching electrical machinery according to a set pattern for the past forty years. It will be a little difficult to convince him that Blondel's double reaction method must give way, for example, to a discussion of how to select and assemble the components of a portable rotating machinery set to supply 250 watts of dc at 1,000 volts and 500 watts of 60 cycle ac from a six-volt storage-battery supply.

It is very likely that reactionary opinion will attempt to discredit the proposed program with the claim that it leads to overspecialization and abandons the traditionally sound policy of a broad basic engineering education. This criticism will particularly be forthcoming from those individuals who find their pet subjects partly or wholly scrapped. Even if in the new program it is necessary to curtail engineering drawing from two terms to one, or to eliminate steam engines and boilers, such criticism is unjustified. For material of this sort is no more broad and basic than the strong continuity of mathematics and physics subjects advocated here. In fact the fundamental theoretical basis for engineering has a better right to be regarded as basic than a lot of detailed engineering practice, some of which is fast becoming obsolete.

Reactionary opinion is and always has been an unwillingness to recognize the fact that the passage of time brings about obsolescence in the best laid plans. In many cases such unwillingness is due to mental fatigue resulting in a desire to avoid competitive encounters on new fields and with new techniques. College faculties traditionally have been amply endowed with such individuals, and it is to be expected that their bulk will again be in evidence when, after this war, progressive attempts are made to adapt the educational structure to the needs of the times. The colleges may allow themselves to be dominated by this influence, or they may conquer it and become leaders in the field. Theirs is the choice to make.

Teaching of Mathematics in the United States and in Germany

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This is a very fortunate opportunity for describing the different ways of teaching mathematics in the United States and in Europe. I was able to accept the kind invitation to speak about the different methods because I have taught about 40 years in Germany and 5 years in the United States. Such a comparison must necessarily lead to a certain criticism, and I shall have to apologize for my frankness in this respect. It may seem pretentious on my part to criticize some of the methods used in the United States because I am not yet a citizen—I hope to be a citizen in the course of this year—but there are two good reasons why I think I can express these critical remarks. First, education in the United States has so many advantages over the education in Germany that even some critical remarks about some of the methods in scientific education will easily be pardoned; and second: It is the duty of each educator, if he sees the possibilities of improving education, to raise his voice for the accomplishment of these improvements. The United States will play a preponderant rôle in the reëducation of the misled people in Europe, education here to serve as a model; and it is also important, for the security of the United States, to have the best possible scientific education as well as education in general. A first class mathematical training is nowadays necessary for all the applications in the interest of the defense of the country; for the Army, the Navy, and the Air-Force; and for the well-being of the nation as a whole. We are passing through a time of war, and therefore I mention first the needs of the armed services. Even when peace comes, we shall not be sure that this will be the last war. The United States will always have to look out for the best means of defense, for the best armaments, for the best communications and for the best technical methods in all the different branches of production for the well being of the nation. More than ever before mathematical knowledge is necessary for much wider circles than in the past.

If one first compares in a very general sense education in the United States and in Germany, every teacher coming from Germany to the United States is struck by the higher *political* and *moral* education of the average young American. This is largely due to the *democratic* institutions, to the ways in which history is taught, and to the choice of reading in the schools. In Germany, even during the republican period after the end of the first world war and until the rise of the Hitler gang, there remained always a trace of the old autocratic and mili-

taristic education in the spirit of many school teachers, in the textbooks, and in the methods of teaching history. So the boys between 15 and 20 did not have the same political and moral education in Germany as the boys in the United States. Intentionally I omit here the influence of the religious teachers working in all the countries alike for the improvement of *moral* education.

This very great advantage is not found, however, if one compares scientific education in the United States and in Germany, and I will now confine my comparison to the field of education in mathematics and physics, including chemistry, and to the field of their technical applications. In Germany the student normally come to the University or Institute of Technology one year later than the young American leave high school to go to a college or university. At least this was the case until a few years before this war when the last year of the "gymnasium" (corresponding roughly to the high schools here) was cut off, a measure taken apparently in preparation for this war in order that the better instructed young men might be ready for military training. So if we discount this recent measure, the young German student had an advantage in comparison with the young American student, especially in all the sciences where a mathematical background is of importance. High school boys in Germany could decide a few years before leaving high school whether they preferred humanistic studies or sciences where a better mathematical background is needed. I may say that those who chose a humanistic instruction were at a not much higher level than the average American boy leaving high school, but *those who chose scientific instruction with more mathematical background came out much better prepared for this technical century.* They had in their last year studied calculus and spherical trigonometry, and their knowledge of arithmetic, geometry, and plane trigonometry was much deeper than the mathematical knowledge of the average American boy leaving high school. One may remark that this deficiency in mathematics could be compensated by a year of preliminary mathematical instruction in college for those who need a better mathematical background, and this would be so much better since the average American boy comes a year earlier to college.

Unfortunately the usual schedules of the colleges do not provide such preliminary mathematical instruction, especially in calculus. In some engineering colleges, *e.g.* at M.I.T., Stevens Institute, and several other technical colleges, students get some mathematical instruction in the freshman year, including calculus, but in the same year they have their first instruction in physics or engineering problems. The consequence is that they are in the beginning wholly unprepared for the study of physics and engineering problems, and the textbooks and lectures in general physics must allow for the fact that the student cannot yet apply the notions of calculus. *Some important parts of physics,* I may say, *basic* parts, *need the knowledge at least of some fundamental notions of calculus.* The textbooks and lecturers in general physics go around the difficulties: either they give formulas to memorize like dogmas, or they give "so-disant" proofs in round about ways which are rejected by the more intelligent students as incomprehensible and are taken for granted only by the less intelligent, accustomed to the au-

thority of the textbook and the lecturer. The authors of these textbooks in general physics had no other choice, and *here we have really to improve something. This state of things must be changed after the war,* unfortunately it is too late for this war.

Again I must apoligize for my presumption in criticizing customary instruction-measures, but I feel it is my duty to direct the attention of the authorities to *this drawback which has damaged the preparation of officers—especially the officers of the Navy and the Air-Force.* I am proud to have given lectures in general physics to quite a number of the Navy boys on their way to become officers; mostly they had only the background in mathematics of the average boy leaving high school, so they had no knowledge of calculus, and *even their knowledge of arithmetic and trigonometry was rather poor.* I was in the same dilemna in which are most of the lecturers in general physics and authors of textbooks.

If in the last year of high school these students had learned at least the fundamental notions of calculus, it would have been possible—to begin with one of the simplest notions in mechanics—to explain what is velocity and what is acceleration. Of course they were able to understand "mean velocity" in a certain time-interval (they knew how to consult speedometers in motor-cars); but the notion of true velocity, for instance of a freely falling body, could not be clearly explained, and so the notion of acceleration and all the other important notions having to do with acceleration remained obscure. Other difficulties arose when the rotational inertia of a rigid body was considered and some formulas were given which the students had to memorize. I have always chosen the open way, telling the students: "You cannot understand these formulas without a knowledge of calculus." I have rejected the method of "soi-disant" proofs avoiding the notions of derivative and integral; but I had anyhow the feeling of regret that the students could not understand the full meaning of these important things, important not only scientifically but technically. How much easier and more effective this instruction would be with students having a little more mathematical background!

The expression "rate of change," which has to replace in some general laws the notion of derivative, remained obscure to most of the students; when in the discussion of electromagnetic phenomena the induction-laws were treated and the laws for alternating currents with their applications in radio, again one had to say: "you must learn all the formulas by heart; to understand their connection you must know a little more mathematics." Of course it is possible to give a certain superficial instruction in physics in this way, but how much more effective would be the knowledge, if the students got a real deep understanding of the different phenomena; how much more easily they would grasp all the important applications—they would serve the country far better. Is not that reason enough to change the present obsolete schedule of the last year in high school?

The Germans had formerly the advantage of better preparing their boys in mathematics in their gymnasium; their recent measure of cutting off the last year of the gymnasium has deprived them of this advantage. Also in Germany in former times the instruction in general physics had for the most part the same drawback as here.

As the lectures in general physics were given also for those who wished to become physicians and for those who were occupied with pharmaceutical studies, the lecturers again avoided subjects which can be understood only with some knowledge of calculus, knowing that many of the future physicians had chosen the humanistic schedule in the gymnasium. But anyhow those who had more mathematical background derived immensely greater profit from these lectures in general physics than the other students, and the real advantage the German student had, when he was well prepared in mathematics by his gymnasium teachers, cannot be overestimated. I recommend to the serious attention of the authorities my conclusion that after the war the schedule of the high schools in the last year must be revised in favor of more thorough mathematical instruction.

If the teachers of mathematics and physics in high schools have to teach at least the foundations of higher mathematics, their level will also be raised. There is no doubt that the routine of mathematical teaching without paying any attention to higher mathematics leads to a stagnation of the interest which the teachers at the high schools may have for modern progress in mathematics and physics. There are of course excellent exceptions, but everybody will agree with me if I say that with the teaching of higher mathematics the contributions of the high school teachers to scientific progress will increase.

After having discussed this very serious matter, in which I think it is my duty to include some criticism of the American system of teaching, I come now to another subject showing a great advantage of the American way of teaching mathematics at the colleges. In most of the lectures in mathematics in Germany the professor has no contact whatever with his students. He gives his lecture, mostly well prepared, having his manuscript on his desk, without being interrupted by any student's question, and on rare occasions meeting with some approval for a funny remark. The students show their approval by stamping their feet, the same stamping which greets the professor when he begins his lecture. At the big universities there are sometimes many hundreds of students attending a lecture. So the professor does not know his pupils in general, since there is only a small number of students who also attend the so-called seminars—lectures in which the professor treats some special problems in the American way. Here the student can discuss some questions with the professor, and the professor assigns at each lecture some problems, the solutions of which the student has to hand in at the next lecture. There is only a very small number of students attending these seminars, and only here has the professor any opportunity of knowing some of the students personally and of judging their progress. Something similar can be said about the lectures in general physics and chemistry. Again there are at the big universities and institutes of technology many hundreds of students attending these lectures, which are also obligatory for physicians as well as for future teachers of mathematics and physics. The professor is very proud to have especially large numbers of students, and his salary was formerly increased according to the number of students, so that the lectures of general physics and chemistry brought very high incomes. But the professor did

not know his students; only in the laboratories did he have an opportunity of knowing some of them. It is true at the big Universities and Institutes of Technology he passed through the laboratories like a king, asking only superficial questions, such as whether they liked their work, whether they found it difficult and so on, leaving the routine work to his assistants. Only a few predilected students had the ptivilege of discussing with the professor their work, when they worked on a thesis or on a special research subject.

So the difference in the American and German ways can easily be seen. The way of teaching in the United States is much better for the *average* student. Here the professor has an interest in each of his pupils; when the student is weak, the professor will try to help him, finding out where the trouble is. He cannot teach more than perhaps 30 students; otherwise he could not make contact with each of them. It may be that the care for the best students cannot be so great as in the German way, where only the best students enjoy the special interest of the professor and are encouraged in special performances. It is true that Germany by these methods has discovered her great scientists, since the average students were neglected, and only the best were selected for special aid and encouragement. Perhaps we can find a golden mean between the two methods, each of which has its advantages. It has often been recommended as a solution that the first scientists be permitted to dedicate themselves exclusively to research work, with perhaps some elective lectures for advanced students, among whom the later aces may be found, and that the routine lecture initiating the student be held by assistants. This method has been rejected in Germany, and with good reason. The initiating lectures, *e.g.* in physics and chemistry, are often decisive in the career of the young man. I may confess myself that lectures by the great physicist Warburg which I heard in my freshman year dealing, for instance with Maxwell's ideas about the electromagnetic field, have had very great influence on my later work. It is important whether a first class man illuminates these initiating lectures by the sparks of his genius or whether a second class man makes a routine out of this job. So it will always be good to give to the first scientists the opportunity of teaching also the average student and to raise the level in this way, eventually in the way, as it is done in Germany, in lectures which a great number of students may attend. Besides this there will be initiating lectures given by assistants in the way of so-called recitation-lectures for small groups of students, in which the instructor takes also special interest in the weaker students, in order to raise the average-level. Great scientists will not be very much disturbed in their research work by such lectures, and as the care for the weaker students will be left to the assistants, they can turn their interest to the most promising students.

Raising the average-level is sometimes called the *democratic* method, and the *preference given to the more intelligent student* an *aristocratic* method; I think it is not right to use these words in scientific education in the sense that in a democratic nation the raising of the average-level is more important than the special encouragement of the more intelligent. One is as important as the other. I may even

say that the emphasis upon the so-called aristocratic method may be greater in scientific education than in political and moral education. Every student has the same right to education, but when by and by the more intelligent excel—good care must be given of course also to their moral qualities—there is no antagonism against the ideals of the United States in giving to these superior students more attention and encouragement. They will work for the benefit of the whole; they will be the pioneers of progress for later generations. So after my first recommendation about the mathematical schedule in high schools, my second serious recommendation is *the care for the superior students.* It has been a blessing for education in the United States that so many rich people have given money for scholarships to enable poorer students to attend colleges. Likewise such gifts are useful in enabling advanced students to do more research work. In physics, chemistry, and especially in electrotechnics the German universities and institutes of technology were well equipped for research work by advanced students. Here in the United States, although much money is spent, especially in these times of war, for the solution of special problems by professors who have proved their abilities by their former work, *in most of the colleges the equipment for research work of advanced students is poor. The advisers of rich people who wish to spend money for the benefit of the nation, ought to direct the attention of these rich men to this opportunity of procuring the necessary equipment to enable seniors and graduate students to do useful research work.*

I come now to some more special questions about the different subjects, especially in mathematics and physics, which were taught formerly in different ways in Germany and the United States. The general trend is now in the direction of equalizing the different methods; one nation learns from the other, and one tries to choose the best. Formerly there was more need in America for the solution of relatively easy engineering problems. Pure mathematics was treated only so far as its utilization for later practical applications was seen, whereas in Germany, France, and England there was a fair number of great mathematicians who treated mathematics without any aim of applications; mathematics became an art admired for the beauty of its methods, and the thought of practical applications even spoiled its glory for many scholars. Things have utterly changed in this century. The old Europe with its preparation for war has shifted more and more from pure mathematics to applied mathematics; there are only a few mathematicians who despise applications, occupied, *e.g.,* with the theory of several complex variables. But the greatest progress has been made in the endeavor to solve problems in hydrodynamics and aerodynamics to serve the construction of planes and airships, and in the field of electrotechnics. Even the field of integral equations which was first classed as a field of pure mathematics has been treated more and more in a way to serve applied investigations. With American mathematicians the trend has been just the contrary. American mathematicians have seemed to enjoy to a much higher degree than in the past century the beauty of purely mathematical methods; and applied mathematics, especially hydrodynamics, aerodynamics, theory of elasticity, and theory of wave-

motion, are treated mostly by scientists coming from Europe—from Russia, Hungary, Austria, Germany, France, and Belgium. It is very probable that this trend has resulted from the relative security which the United States enjoys, thanks to its favorable geographic situation; only recently, because of the development of aviation, the danger has appeared also at the doors of the United States, and in consequence the necessity to give the preference to problems of applied mathematics has been recognized. Already some time before the outbreak of the war an important organization of courses in applied mechanics was started by Dean Richardson of Brown University in Providence, R. I., and this was the signal for the majority of American colleges to turn the subjects of mathematical teaching toward applied problems. No doubt there is good reason for such a development; it is trivial to say that this war is a war of technicians, but we must not forget that the progress of technical inventions and industry comes from solutions of mathematical problems. *Therefore we mathematicians have to dedicate all our efforts and all our time to the progress in mathematical methods serving the improvement of the means of defense of this country and the victory of the Allies, to research and teaching in this direction.* Just as art must suffer when the artist must become a soldier on account of the grim necessity of war, so the artistic beauty of pure science practiced without the aim of applications must be postponed. The Germans have been doing this for some time, when they were preparing for this war, and the Allied countries cannot but choose a similar program. So I come to my third and final conclusion. As long as this war lasts and for as long as the security of the United States demands it, *teaching of mathematics must have its principal aim to educate our students in the methods which can serve the defense of the country and the victory of the Allies; mathematical methods serving in physics and chemistry, applied to the production and the use of weapons, and to the maintenance and improvement of communications and supplies:* in two words APPLIED MATHEMATICS. They will help to win this war, and they will be useful also thereafter.

Adaptation of the Coöperative Method to the Railroads*

By H. J. HOGLUND

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Introduction

It seems to me I should first tell you how I became interested in this plan of coöperative education. At a conference not long ago between President Budd of our railroad and President Emeritus Scott of Northwestern University, mention was made of the existence of such plan on another railroad. I was delegated to develop the plan and, after ascertaining these facts, it became my duty to communicate with Dean Seulberger of Northwestern University and my pleasure to assure him of our desire to avail ourselves of the proposed plan.

Casualties of Employment Opportunities on Railroads

With the advent of new forms of transportation, very largely subsidized in one way or another, came the end of railroad expansion. It is generally conceded that in the light of the various forms of transportation available today there are many miles of railroad that would not have been built if the pioneer builders could have foreseen subsequent events. In its wake followed the vicissitudes of the depression. All of this contributed to a decrease in the number of college trained men needed on the railroads. During this period, of course, the employment opportunities were greater in other industries, but in so far as the railroads are concerned there should be more employment opportunities on the railroads in the future. These opportunities will not be in new line construction, but on the other hand, will be in the improvement of the present productive lines of railroad through reduction of curvature and grades and building better cars and motive power.

The American Railway Engineering Association has recognized the future need of college trained men and has for several years had a sub-committee on coöperative relations under the able leadership of E. T. Howson. This committee has developed a great deal of information on the subject, and I judge from some of the reports received from the various colleges that there has been a growing impression that railroads do not need any more college trained men. This is far from true. As a matter of fact, there has not been any lack of interest in college trained men by the railroads, but the inroads of the depression have deferred many otherwise worthy projects that obviously will take shape in the post war period. Because these projects have been held back by the depression and the war, we can look forward to a greater de-

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mand for college trained men in the post war period than at any time since our railroads were built.

In one instance the dean of one of our universities deprecated the fact that he had been advised by a railroad officer that it was difficult, if not impossible, to give special consideration to the employment of college students with unusual promise because of the seniority rules contained in labor agreements. At the same time he admonished the rairoads that, until they make the necessary arrangements to attract young engineers to employment on railroads, they will not be able to make the progress they should make. He suggested that a definite relaxation of regulations regarding seniority should be encouraged as this would be of great advantage to labor as well as management. There are a few restraints in this respect and there are likely to be more instead of less as time goes on, but this should not dampen the effort now being made to adopt a coöperative plan. In any event, I think we can all agree that the railroads are interested in college trained men for the industry. We must not, however, overlook the fact that some outstanding employes without college training, who have gained valuable practical experience while the student is in school, will continue to compete for promotion to executive positions.

Plan

The plan already conceived is a relatively simple one, and because of its simplicity, I sincerely believe it has some possibilities not heretofore considered, at least not by those of us who have pondered how to fit into our organization the student who has gone to school the required length of time and received his degree. This has been difficult of attainment because the individual is not attracted to the lower paid positions where the fundamental experience is acquired. The plan under consideration is for the student to take a five-year course in one of the following degrees:

B.S. in Mechanical Engineering
B.S. in Electrical Engineering
B.S. in Civil Engineering

This contemplates that the student will spend the first year from September to June in college. The summer following the freshman year is a vacation period. At the beginning of the second year, the program of alternation between college and the railroad job is started. This is on a three-months' basis, and during his period on the railroad the student works just as any employee of the company; that is, he is completely away from school, has no class work, and is solely under the jurisdiction of the railroad.

This is the way the student is provided with the practical experience in railroad work before he receives his degree. The railroad is thereby enabled to select and bring young men along in its organization who should become valuable to employ after graduation. This plan further contemplates working students in pairs; that is, while one man is in school, the other man is in railroad service, so that one position is continuously occupied by two students alternating on a quarterly basis. It is likewise expected that the student will remain with the same railroad throughout his college career and that his practical experience will be reasonably diversified. The rate of pay should be the same as paid other employes in similar positions.

Selection of the student may be made either at the school or at the

railroad company's offices; and there is no obligation to use any specified number, so that the railroad is left entirely free, if it chooses to do so, to make its plans on the basis of actual needs of the service.

Restraints

While we are developing the possibilities of the plan under consideration, it is also necessary to point out the restraints. To secure a comprehensive picture of the whole situation we must begin with the legal requirements of the Railway Labor Act. This law (enacted on May 20, 1926, and amended June 21, 1934) provides, among other things, for voluntary organization of subordinate officials for the purpose of collective bargaining. I quote Section 1-Fifth of the Act:

"The term 'employe' as used herein includes every person in the service of a carrier (subject to its continuing authority to supervise and direct the manner of rendition of his service) who performs any work defined as that of an employe or subordinate official in the orders of the Interstate Commerce Commission *now in effect* and as the same may be amended or interpreted by order hereafter entered by the Commission pursuant to the authority which is hereby conferred upon it to enter orders amending or interpreting such existing orders."

The Interstate Commerce Commission, in Ex Parte 72, has defined the term "employe" to include certain subordinate officials. It includes, for example, civil, mechanical, electrical and other technical engineers inferior in rank to engineers of maintenance of way and Mechanical Department Shop Foreman inferior in rank to General Foreman. With very few exceptions, technical engineers are not at this time represented on railroads for the purpose of collective bargaining. To whatever extent they may hereafter seek such representation and to whatever extent the terms of collective bargaining agreements may provide restrictions, will depend the freedom of employment of students after graduation in such positions.

Post War Possibilities

I would like to take up now the possibilities for practical training in electrical and mechanical work (where labor agreements actually are in force) during the student's scholastic career referred to heretofore. I think I am safe in saying that every railroad has an apprenticeship rule in the collective bargaining agreement covering these two classes of employes. They may not be exactly the same on all railroads, but, generally speaking, they are similar. As a general rule, applicants for regular apprenticeship must be between the ages of 18 and 25 years, and must serve four years of 290 days each before they are considered qualified as mechanics.

Mechanics' helpers may also be selected as apprentices after two years of service, and they must be between the ages of 21 and 35 years. They are required to serve only three years of 290 days each.

All apprentices must be indentured and are furnished with a duplicate of indenture by the company. You may be interested in the form of indenture. It provides:

"This will certify that.....
.....was employed as.....
apprentice on.....Railroad at
..... on ....., 19....
to serve (3 or 4) years, a minimum of 290 days each.

.....
(Title of Officers in Charge)"

The ratio of apprentices in their respective crafts on our railroad must not be more than one to every five mechanics. This varies on the different railroads. I recall seeing an agreement on another railroad where the ratio was one to ten.

It is permissible for regular or helper apprentices in metal crafts to be transferred from shop to roundhouse, or from roundhouse to shop, for the purpose of training them as mechanics.

Our Railroad has no written rule with reference to diversification of work by an apprentice, but most railroads have a rule of some kind. Generally speaking, however, the labor unions with which we deal advocate the following for machinists:

"Apprentices shall be given an opportunity of learning all branches of the trade. They will serve 3 years on machines and special jobs. Apprentices will not be required to work more than four months on any one machine or special job. During the last year of their apprenticeship they will work on the floor."

For electrical workers they advocate:

"Apprentices shall be given an opportunity of learning all branches of the trade. The various classes of work are designed as a guide and will be followed as closely as the conditions will permit.

12 months—inside wire and electric repairing
6 months—outside line work
6 months—locomotive headlight work
6 months—car lighting department
6 months—armature winding
12 months—general electrical work"

Obviously, none of the students would utilize this apprenticeship for the purpose of becoming journeymen mechanics with at least two more years of apprenticeship still to perform under the rules because they will aspire to better positions when they finish school. However, the ratio of one apprentice to five mechanics, or even one to ten, should furnish ample opportunity for every railroad to coöperate with colleges in the plan outlined. It might be said, and not without some foundation in view of the language of the Indenture form heretofore mentioned, that the labor unions will object to an arrangement where it is known at the outset the men are not going to utilize the apprenticeship for the purpose of becoming journeymen mechanics. Frankly, I do not believe the labor unions will be prone to take such a position, because many of the students will be the sons of mechanics in the shops and the union leaders, I am sure, rely upon the will of its membership on policy questions of this character. At any rate, at the appropriate time, this could well be discussed with labor representatives involved in the light of the rules as they now appear in the individual agreements. As a matter of fact, I understand an agreement is in existence on an eastern railroad providing for short apprenticeship of college graduates.

In so far as the coöperative plan is concerned, our Mechanical Department officers tell me that a schedule of apprenticeship during a mechanical engineering student's scholastic career should be about as follows:

9 weeks operating a shaping machine
9 weeks operating a lathe
9 weeks operating a boring machine
9 weeks operating a milling machine
20 weeks on the erecting floor
9 weeks on pneumatic devices such as power reverse gears, etc.
9 weeks on roundhouse maintenance work
30 weeks in drafting room

For an electrical engineering student, I am advised it should be about as follows:

20 weeks Diesel-electric locomotive maintenance
12 weeks passenger car air conditioning maintenance
8 weeks passenger car lighting maintenance
8 weeks shop work, motor repairs, etc.
8 weeks shop work, passenger car wiring
6 weeks shop work, storage battery repairs
6 weeks roundhouse maintenance, mostly locomotive headlight work
18 weeks system electrical road force on wiring, installations and maintenance, both inside wiring and line work
18 weeks estimating, inspecting and testing in connection with wire installations

There has never been any definite plan of apprenticeship or training in the civil engineering department. Heretofore it has been the practice to employ young men having necessary education and aptitude to fit into the position for which they were employed, and then, as they gained experience and opportunity presented itself, they were advanced. Our engineering department officers feel that under the cooperative plan an arrangement could be placed into effect as follows:

24 weeks as second class rodman
24 weeks as first class rodman
24 weeks as junior instrument man
32 weeks drafting room

If the work in progress on the railroad permits, it would be very desirable if the student were placed with a gang doing track work, such as laying rail, ballasting track, etc.

There are not now any labor agreements—at least not to my knowledge—which will interfere with the use of a student in a civil engineering party during his scholastic career, nor should there be any great difficulty in providing diversified training as heretofore mentioned if work in progress on the railroad permits.

Assuming that all these minor details can be met and that the plan is placed in effect, the contact made with the individual during the previous four years should enable the railroad to appraise the qualifications of the students at the time of graduation and determine just where, assuming there will be vacancies and new positions to fill from time to time, they will fit into the railroad organization as inspectors and estimators in the Mechanical Department and junior engineers in the Civil Engineering Department. It removes much of the doubt about personnel for promotion inherent in selections made in any other manner. Promotions later on to positions of greater responsibility will depend upon increased aptitude for leadership and appetite for hard work. There is, of course, no substitute for hard work and that must be considered in all cases of promotion.

With respect to the suggestion that seniority rules be relaxed, obviously this is not always possible, nor is it entirely the answer. The relaxation should be in the Order of the Interstate Commerce Commission which permits certain subordinate officers to be classed as employes for the purpose of collective bargaining. There is only one other avenue open to clear the way of restrictions, and that is to secure a change in the law granting these powers to the Commission.

The original purpose underlying the principle of seniority was to provide some measure of security to employed workers and to serve as an index to be

used when it became necessary to separate them from gainful employment during periods of economic stress. Seniority first emerged in the railroad industry in the 1880's, when tenure of employment was precarious. The movement grew slowly, spreading from West to East and from craft to craft, until it became definitely established under Governmental wartime administration during the First World War. It has also, of course, gained a strong foothold in numerous other industries, especially the printing trades, and is even now making rapid progress in the automobile and steel industries. Seniority rights stem exclusively from collective bargaining agreements between labor unions and management. The provisions range from a short, simple sentence recognizing the principle to an elaborate code of detailed regulations. The administration of seniority is ordinarily entrusted to the employer. Unjustified departures from the principle laid down are considered grievances, and various procedures have been provided for their redress. While the seniority rule is usually called into play when force reductions, reinstatements and promotions are involved, the scope of these three aspects is not always defined with precision.

Conclusion

It is perhaps too much to hope for any relaxation in the orders of the interstate Commerce Commission or a change in the law which permits representation of subordinate officers for purposes of collective bargaining. Therefore, our only hope lies in the fact that not much headway has up to this time been made in representation of the technical and other supervisory people who fill the positions which should be open to students we are considering after graduation. Railroads hereafter faced with negotiating agreements covering any of these positions should certainly keep this coöperative plan in mind and seek to write seniority rules which will not unduly impair the avenues of promotion of such graduates.

Industrial Research Curriculum Requirements*

By GEORGE E. ZIEGLER†

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The great emphasis that is now being placed on "new products" in all of our discussions of post-war economics makes a vital issue of our future educational plans for providing a sufficient number of persons adequately trained to develop all of these promised new products.

Certainly the building of a college curriculum for industrial research is an important step in attaining an adequate future supply of the necessary research and development personnel. The establishment of an industrial research curriculum, however, is not a simple matter because industrial research itself is not simple.

Considerable material already has been written on the subject of training men for industrial research. The present paper, however, deals entirely with the personal observations of the author and recommendations from his industrial research associates who have shown much interest in the subject.

It is not the purpose of this paper to suggest a fixed course of study, but to point out objectives that are required for industrial research curricula. Much of the ultimate success of such a curriculum depends upon the interest and enthusiasm of the instructors, as well as their viewpoints and the emphasis they give to selected subject matter. With the required objectives actively in mind practically any thorough engineering or science curriculum can be converted into a good industrial research curriculum.

Preliminary Considerations

Before any specific attention is given to the educational requirements for this growing field, the nature of industrial research and its potentialities as a profession of the future should be considered.

Probably the most widely accepted definition of industrial research is that given by the National Research Council in its "Directory of Industrial Research Laboratories of the United States," published in 1940. This definition reads:

> Industrial research is the endeavor to learn how to apply scientific facts to the service of mankind. Many laboratories are engaged in both industrial research and industrial development. These two classes of investigation commonly merge so that no sharp boundary can be traced between them. Indeed, the term research is frequently applied to work which is nothing else than development of industrial processes, methods, equipment, production or by-products.

From this definition it is evident that industrial research includes a whole range of activities from pure science through engineering of various kinds, to cut-and-try development work. Some of the greatest successes in in-

* Based on paper presented at Chicago meeting of S.P.E.E. (Physics), June 18–20, 1943.

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dustrial deveopment for our national war effort have been achieved through various combinations of pure science, engineering, and cut-and-try methods.

A problem now confronting the educator, who is making plans for the future, is that of evaluating the demands of industrial research for well-trained students in the post-war economy. All evidence now available indicates that it will be necessary in the post-war period for the colleges to develop many more potential industrial researchers than have been required up to the present time.

This evidence for an increased demand for industrial researchers is manifold. Industry, during the past few years, has found that research pays real dividends which can be measured in dollars. In nearly all cases, the dividend rate from research has been attractively high. Many business men also consider research expenditures as insurance for success in manufacturing the products of the future. Industrial research has impressed business so favorably that many organizations are now willing even to aid so-called fundamental or pure science by allowing a portion of their research budgets to be spent on fundamental work at universities or colleges and research foundations.

Another factor in the evaluation of the future of research, which cannot be overlooked, is that research is now "in style." This fact is presented daily in news items and in the advertisements that appear in many magazines and newspapers. Many of the leading manufacturing companies have no products to sell today because of 100 per cent war material production. These companies cannot afford to pass out of the public eye. Through their advertising they now are creating in the minds of the public an appreciation of the wonders research can do for manufactured products after the war. Research is thus gradually becoming an accepted element in our economy.

Another small but significant point indicating present industrial trends is the fact that more and more companies are elevating the position of their Director of Research to the rank of a full Vice President, thus for the first time putting research on an equal footing with production and sales. Banks are also considering the research activities of companies in determining their acceptability for loans.

Actual statistical data on research activity likewise point to a steady increase in the demand for industrial researchers in the post-war period. In 1940 the National Research Council reported the existence of 2,264 industrial research laboratories employing about 52,000 workers spending an annually estimated $260,000,000. At first sight it might be thought that American industry could not afford to increase further its research expenditures but the following consideration shows that this is far from true.

The better and more successful companies for the past years have been spending as much a 4 per cent of their total income for research and development. All companies are not equally progressive, thus a figure of 2 per cent of total income might be a reasonable average figure for all companies to spend on research. Suppose after the war our national income shrinks to only 50 billion dollars. At 2 per cent the total research and development expenditures could very well be one billion dollars which is four times the 1940 expenditure.

If a curve of research expenditure vs. time is plotted for the past years and

simply extrapolated for the next few years, similarly significant increases are indicated.

Without even mentioning the tremendous impetus that is being given to industrial research by the war the evidence is overwhelming in indicating that there will be a continued increase in the demand for industrial researchers.

In the past, most industrial research workers have found it necessary to be "self made." There have been only a few serious attempts at actually training men for this field. Opportunity for research experience of course, has helped. For example, the Armour Research Foundation has trained industrial researchers by making it possible for science and engineering graduates to engage in industrial research. Likewise the industrial research organizations of universities have provided a limited number of opportunities. Although this type of approach to the problem has provided industry with some very accomplished research people, the total number that can be so supplied is altogether too small.

Required Characteristics

Even a casual inspection of requirements for industrial researchers shows that it is impossible for any one individual to possess a full measure of all the requirements. Nevertheless, for a program of industrial research to be successful all requirements must be achieved either individually or collectively. Only when each member of a group shares his own particular talents with the others can real completeness be achieved.

The following sections set forth characteristics which should be developed by any successful industrial research curriculum:

1. The ability to work with others is of the utmost importance and a successful curriculum must provide an opportunity for the development of a spirit of true coöperation. Naturally, individual initiative and individual abilities in particular fields are requisite, but these produce maximum results for industrial research only if accompanied by coöperation. Most industrial research problems are so complex that they can be solved only through the collaboration of several researchers expert in different fields.
2. A researcher must be expert in carrying out at least one of the various branches of research, such as:
   (*a*) Experimental research.
   (*b*) Mathematical investigations which can serve as a guide for experimental work.
   (*c*) Experimental engineering research to transfer the results of basic research to pilot-plant operation.

   The experience and training for any one of the above fields can be obtained by most people only through work at the graduate level. Men lacking graduate training usually experience difficulty in advancing beyond the research assistant stage. This deficiency is not easily overcome even by long experience. If experimental research is to be the student's objective, it is necessary that he master in school as many experimental techniques as possible, because there are so many new things to learn after he starts to "work" that there is little time available for practicing techniques.

It is essential that experimental researchers be able to use their hands skillfully. Along this line, a small amount of good machine shop instruction gives the researcher a surprising freedom and ability to proceed quickly with his experimental setups. Likewise experienced glass blowing instruction will avoid endless hours of attempts at assembling equipment. As research laboratories are established by the smaller companies, they will necessarily be of restricted size. In these the independence possessed by a man skilled in laboratory techniques will give him a unique position.

3. A researcher needs ability as a salesman. All new ideas and developments have to be sold. This is sometimes difficult even to fellow researchers, especially if the idea is something genuinely new. The selling of ideas to the production engineer is even more difficult but is, of course, indispensable if the industrial research group is going to justify its existence through new products. The selling of ideas is almost synonymous with report writing. Too much emphasis cannot be placed on the development of ability to present ideas in clear, convincing words, and if these clear convincing words can be supplemented with an element of human interest, the researcher has an asset of great value.
4. Good data-keeping habits are indispensable to an industrial researcher. In his daily experimental work he is determining new facts. Many of these facts will not be used at once; they may be either negative results or just not of value to the problem at hand. However, at some time in the future these very data may be the answer to another problem, provided they can still be interpreted. American industry is dependent on the patent system. Accurate, well kept research records often prove to be of very great value in patent matters. Neat, accurate, original data sheets for every class room measurement will help the student develop fixed habits of keeping good data. The keeping of proper records in the laboratory goes a long way in helping a student develop the high degree of intellectual honesty needed for good research. Research can be ruined by prejudice and poor records.
5. The researcher must develop a keen admiration and appreciation for high-grade mechanical, optical, electrical or other experimental equipment. It is this appreciation which will permit him to evaluate wisely the worth of new equipment. Wise expenditure of the equipment budget is of paramount importance to the success of an industrial laboratory. Contrasted with the problem of acquiring new equipment is the problem of disposing of it when it has outlived its usefulness. Naturally, this disposal requires careful analysis of values. Further, the making of precision measurements is stimulated if the whole laboratory has an atmosphere of care and precision.
6. An active knowledge of the history of the famous men and early experiments in science is of surprising value as a background for modern industrial measurements. Frequently the ingenious experimental devices of classical physics or

chemistry and the equations of advanced abstract mathematics can be directly employed with very slight modifications. Achievements of the past are always encouraging to present day workers.

7. The industrial research worker needs an active interest in practical industrial processes. Even though the researcher may be permitted to pass along his new ideas to a process engineer for the details of production, it is quite necessary for him to make an early estimate of the feasibility of his new idea. Otherwise, it becomes very hard for him to interest others successfully in pushing the idea along. Nor is it too much for management to expect a researcher to appreciate that it is the financial return from the practical processes that pays his salary.
8. It is imperative that a researcher have unquenchable imagination and vision. Only the genuine researcher has the background from which to imagine new products and new processes. The production engineer can work out process improvements but, in general, his experience and background, if he is a true production man, are such that he is apt to think only along certain well established lines. If the production engineer did not resist continual change, there never would be any quantity production. Imagination and vision, on the other hand, should be among a researcher's most active faculties.
9. Patience and persistence, almost without end, are required to pull research projects through those periods that are often referred to by industrial researchers as the "doldrums of research." This patience and persistence must be accompanied by a strong element of enthusiasm. In fact, enthusiasm must prevail in a research laboratory or else creative work will cease and the laboratory will turn into a testing bureau, probably testing only ideas presented by outsiders. Patience and persistence can be maintained only through a never-failing confidence that results can be obtained through research methods.
10. A well-rounded industrial researcher should have a good sense of economic values. Although more business organizations are now beginning to permit some fundamental research of the kind that may not lead to immediate profit, the bulk of their research work is expected to produce early results that can be measured in dollars. The measurement of the value of research is no more difficult than the measurement of the value of advertising and this is done every day by all advertising agencies.
11. Industrial research requires ability to make decisions and a willingness to take responsibility. It is the wise decisions to continue promising research or to discontinue research of doubtful future that carry an industrial research laboratory to success. Such decisions often require considerable personal responsibility, because a promising piece of research cannot always be readily recognized.

Our attention, as educators, to these necessary factors of training will influence heavily our national ability to meet the challenge of expanded research.

Engineering Colleges Help Returning Veterans

By R. L. SACKETT
Chairman, Committee on Selection

The S.P.E.E. Committee on Student Selection asked its members to state in brief what special provisions their institutions had made to counsel with enquiring, entering or returning veterans.

The replies reflect a variety of organizations to care for special cases. It was suggested that they might be of help to institutions which were planning ways and means of meeting the educational problems of veterans interested in engineering.

To the five replies which follow by Messrs. Fuller, Bingham, Plank, Krathwohl and Switzer, members of the committee, there are comments collected and provided by President Cullimore, Chairman E.C.P.D. Committee on Student Selection and Guidance. These refer to institutions in the New York area only.

Iowa State College has in preparation, for distribution late this fall, a pamphlet with the purpose of presenting to returning veterans the possibilities for further education at Iowa State. The plans include, after formal registration, the assignment of each person to a definite chief counselor who, after appraising the education, experience, and temperament of the individual, assigns him to a counselor who works out a program with him and keeps in touch with him and his work.

The men will be put in regular classes as far as practicable. Special classes will be provided when necessary for efficient and sympathetic treatment. Refresher courses will be available for graduates returning from military service or from industry. The college anticipates that each candidate for rehabilitation will come with a recommendation from the veterans' Administrative Counseling Center.

University of Colorado.—Special aid to returning veterans is provided through the University Council on Armed Forces Services. The Council is headed by a Director who is provided with an adequate clerical force. The various Colleges of the University, as well as the regular testing and guidance agencies, are represented on the Council. Functions of the Council are: to act as a Liaison Agency between the University and the U. S. Veterans Administration or between the University and the U. S. Armed Forces Institute, to study the needs and desires of the veterans and make recommendations to the several divisions and agencies in the University, to arrange for the organization of special refresher and terminal courses for veterans, to arrange combinations of courses leading to special degrees, to advise and counsel veterans.

Lafayette College has recently taken two steps to facilitate the resumption of the education of returned servicemen whose college studies were interrupted by the war. The first of these steps was the creation of a *Veterans' Program Committee* of five members of the faculty and administration. This Committee has instituted the following activities:

(1) Printed a bulletin for the information of all concerned, setting forth the policy of the College concerning veterans' education.

(2) Assist in special problems of admission, conduct aptitude tests, and provide counseling and advice to applicants.
(3) Arranged for refresher courses in key subjects for men who have been out of high school for some time.
(4) Established the principle that appropriate college credit will be allowed by Lafayette for courses completed in the Armed Forces.

The second step taken in the veterans' behalf is the establishment of a *Veterans' Rehabilitation Committee* to provide veterans with any special care they may need in readjusting themselves to college life.

In addition to these educational activities, the James Lee Pardee Placement Bureau has maintained complete records of Lafayette men in the Armed Services, and is correlating its placement facilities with those of the several industries which are progressively pursuing the problems of reëmployment and the rehabilitation of veterans.

The Illinois Institute of Technology has a committee of faculty members with the Dean of Students whose sole function is to handle the cases of returning veterans.

Each veteran is given an interview by the Dean of Students to find out his educational background and the time which has elapsed since he last attended school. Each man is given a great deal of personal time. When there is a question as to whether a veteran is college material, he is given a short battery of aptitude tests.

Georgia School of Technology.—A Rehabilitation Center has been established at this school and a comprehensive personnel program has been installed. Discharged veterans who are found to have a vocational handicap will be eligible for a thorough-going, scientific consultation pointing toward the occupational retraining of those needing such rehabilitation. This program, while operating primarily under the Vocational Rehabilitation Act, is supplemented by the advisement and training program open to all veterans under the provisions of the "G.I. Bill of Rights."

Veterans whose pension ratings included a notation of the existence of a vocational handicap may apply to the Veterans Administration for the services offered by the new Center. Those will include a thorough interview with a psychologist in which information about the man's training, experience, interests and desires will be brought out; administration of a series of psychological measures designed to investigate the aptitudes, skills, adjustment and interests of the subject; consultation with training experts; and finally, if the need for it is established, induction into a course of training, either on-the-job or in an appropriate institution, designed to reëstablish the veterans' employability at their former occupational level.

We plan to have one man to supervise the program, and under him will be two psychologists and two psychometrists. We have already started on this arrangement. Tests will be given, and interviews will be conducted by the supervisor and the two aiding psychologists. As needed various department heads or someone within the department will be called in to aid in the counseling. When it is deemed necessary a psychiatrist will be called in to help. The usual counseling and medical services will also be available.

Alfred University—College of Ceramics.—Regular counseling available, nothing particularly bearing on engineering. Close coöperation with the Veterans Administration at Batavia. Will expand special services to veterans as needed. (John R. Spicer, Counselor.)

Clarkson College of Technology.—Special faculty committee of three for testing, guiding and counselling of discharged veterans. Will develop guidance program for veterans as experience indictates. (John A. Ross, Jr., President.)

College of the City of New York.—Vocational Rehabilitation Center established by the Veterans' Administration.

Columbia University.—Counselling and

guidance handled by regular admissions office. No special organization for engineers.

Cornell University.—Vocational Rehabilitation Center under the Veterans Administration to open November 15th. (Loren C. Petry, Director of Veterans Education.)

Manhattan College.—The Student Personnel Division makes available to the returning veteran its complete facilities for preëntrance guidance, testing, vocational counselling, medical and personal advisement, and placement. (John A. Cossa, Director of Student Personnel.)

New York University.—Regular guidance given at New York University downtown counselling office, and if sent to college of engineering, veterans' records are examined very carefully and recommendations made. Also veterans sent from Veterans Administration in the Bronx. Professor Giannini acts as adviser in the college of engineering.

Polytechnic Institute of Brooklyn.—Same procedures for veterans as for regular students. Interviews are given by Dean Streubel.

Pratt Institute.—Heads of curriculum departments, also the dean, interview veteran candidates for either the engineer or technology programs. American Council on Education tests used for all students of engineering. Engineering Inventory tests will probably be used. Same procedure used for veterans as for other entering engineering students.

Rensselaer Polytechnic Institute.—Vocational Rehabilitation Center established by the Veterans Administration.

Webb Institute of Naval Architecture.—No special plans for veterans. Will give information as requested. Student body now entirely Navy.

A comprehensive Directory of college counselling and placement offices for service men has been published by the Princeton University Press.

Post War Naval Education for Naval Officers

By LEONARD A. DOGGETT

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In looking forward to the post war years the Navy will be faced with the problem of maintaining a much larger commissioned personnel than it ever had before in peace time. The contemporary press reports the Navy with a present war-time strength of some 3,000,000 enlisted men and some 200,000 officers. In July 1940 there were only some 160,00 enlisted men. Our two ocean commitments will certainly require a far larger peace-time Navy than we ever before imagined. It would be fool-hardy for a layman to set the peace-time strength of the Navy for the coming decades but in what follows a tentative figure is used for illustrative purposes.

In order to have a specific number the assumption is made that the peace-time strength of the Navy will be 1,000,000 enlisted men. Provision must then be made for maintaining a commissioned personnel of some 70,000 officers, 42 per cent ensigns and junior grade lieutenants, 30 per cent lieutenants, 15 per cent lieutenant commanders, 8 per cent commanders, 4 per cent captains and 1 per cent admirals.

The prime objective of any proposed system is to obtain the most competent group of men available, provide equal opportunity for advancement to all, and provide an attractive life time career.

The proposal is best explained by reference to Fig. 1. It is proposed to feed into the group annually at the ensign level some 6,000 men, 2,000 from United States Naval Academies, and 4,000 from College and University Naval R.O.T.C. Units. In an eight year period this would represent an input of 48,000 officers. There should be approximately one hundred Naval R.O.T.C. Units, each graduating 40 ensigns. There should be a contract between the government and the potential naval officer. The consideration on one side should consist of financial aid in obtaining his college education. The consideration on the other side should be an agreement to serve in the U. S. Navy as an officer for at least eight years after graduation. After the elapse of eight years the officer will have the opportunity to return to civil life as a naval reservist or to take a promotion examination which at that time would represent approximately a promotion examination from lieutenant to lieutenant commander. This transition point, represented on the figure by the heavy broken line, is an important feature of the plan because it assumes that all officers, whether trained in a Naval R.O.T.C. unit or at a U. S. Naval Academy, will take the *same* examination. Into the grade of lieutenant commander will flow the survival of the fittest. It would generally be expected that the majority of the Naval Academy graduates, who usually have committed themselves to a life-time naval career, would choose to take the pro-

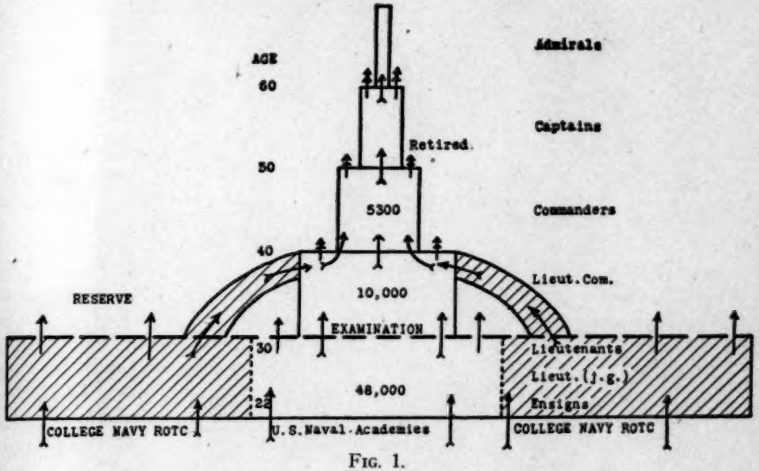


FIG. 1.

motion examination. On the other hand the majority of the civilian trained men will tend to revert to civil life and become members of the pool of trained reservists. In the figure there are shown three types of arrows; the tailed arrow indicates the man who enters the system at the bottom and who may reach the status of admiral; the plain arrow indicates a transfer from active to *reserve* status; and the double headed arrow indicates a transfer from active to *retired* status.

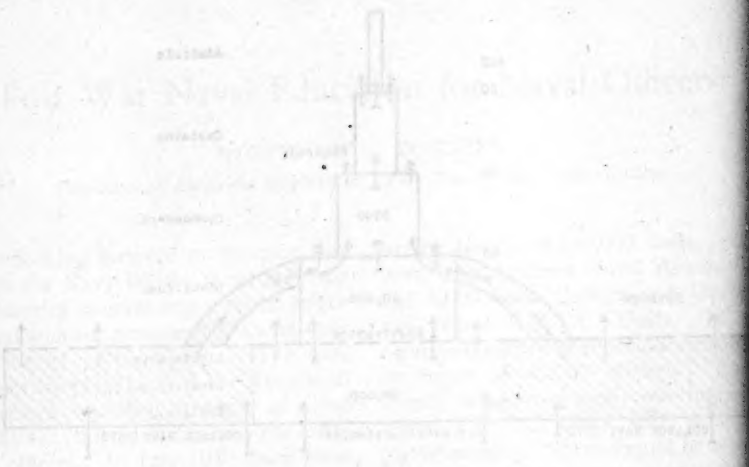
In closing it should be stated again that the numbers used to illustrate the plan are purely symbolic. By using specific numbers, however, clearness in presentation may be obtained. When the size of the post war Navy is set, then it will be possible to modify the diagram proportionately.

The advantages of the plan may be summarized as follows:

(*a*) We place in the commissioned personnel the most competent individuals obtainable.

(*b*) It eliminates any differentiation between reservists and Naval Academy graduates.

(*c*) It builds up a large body of reserves.

The salary of a midshipman in a U. S. Naval Academy is about $780 per year. The allotment of financial aid to a Navy R.O.T.C. student should be of the same order of magnitude. Using this figure and assuming that the maintenance of some 200 Navy R.O.T.C. students at a college will yield 40 graduates per year, the annual cost to the government of maintaining this program would be $15,600,000 for the 100 college R.O.T.C. Units and considerably more than $7,800,000 for the U. S. Naval Academies.

The Navy has had a long experience in operating a Naval Academy and in addition considerable experience in operating College Naval R.O.T.C. units. Although there has been some difference of opinion as to the desirability of locating an Army R.O.T.C. and a Navy R.O.T.C. unit at the same college, our recent experiences with amphibious warfare would seem to indicate the advantage of getting the Army and Navy together as early as possible in their military careers.